



# The Greater Flagstaff Forests Partnership Prescribed/Wildfire Smoke and Health Study Phase I - Methodological Design

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## **Executive Summary**

Prescribed fire is used to mimic the natural surface fire regime as it maintains acceptable fuel levels within the forest, ultimately reducing the risk of large, intense wildfires (Viers 2005). In considering smoke as a byproduct of prescribed fire, the advantages versus the disadvantages must be weighed as well as the alternative, wildfire and the subsequent amount of smoke emitted. Relative size and intensity of wildfires alone have resulted in greater amounts of particulates and other pollutants when compared to prescribed fires that produce less smoke, particulate matter and other pollutants (ibid). Supporting this, a recent study suggests that the use of prescribed fires have slashed fire carbon emissions by 18 to 25 percent in 11 Western states during the years of 2001-2008 (Wiedinmyer et al. 2010).

Adding to the urgency of reducing the probability of intense wildfires is climate change effects. According to a recent presentation by Christopher Fields, who is working with the United Nations' Intergovernmental Panel on Climate Change, wildfires in the Southwest are predicted to increase by 470% per one degree Celsius increase in temperature (C. Field, Stanford University, personal communication).

Trends in air quality monitoring results in Flagstaff have consistently improved since the mid 1980s; the three-year moving average of annual particulate matter (10 microns or less (PM<sub>10</sub>)) concentrations in Flagstaff have noticeably declined by more than 50 percent (approximately 34 µg/m<sup>3</sup> in 1987 to approximately 14 µg/m<sup>3</sup> in 1998) (ADEQ 2008). A portion of this can be attributed to cleaner-burning wood stoves, fireplaces (ibid) as well as improved prescribed fire Emission Reduction Techniques (EMT) and Smoke Management Techniques (SMT) (cited in Sandberg et al. (2002): EPA 1992).

Although advantages of utilizing prescribed fire as a management tool are ostensible, there is a small sector of Flagstaff's citizens that continue to oppose its use. Considering the continued social debate, the Greater Flagstaff Forests Partnership (GFFP) has initiated this study to assess these effects with a study design that includes quantitative data analysis resulting in a definitive causal relationship to assess whether, or not, smoke from prescribed fire has adverse effects on health of the citizens of Flagstaff.

To quantify health effects of prescribed and wildfire fire smoke, the study is delineated in two phases. In the first phase of the study, Phase I, a study design/methodology will be determined through a literature review and by exploring the issue with professionals in the health field, various land management agencies and agency reports. The study design includes three main data collection elements for years 2005 through 2007, which represent both wet and dry precipitation years (2005 - wet, 2006 and 2007 - dry). The three data sets include: 1. health reports of respiratory complaints predetermined by specific, preselected billing codes that represent general respiratory complaints; 2. prescribed fire and wildfire dates, location and burn types and; 3. Arizona Department of Environmental Quality (ADEQ) reports.

The goal of Phase I of the study is to develop a workable methodology that includes data collection methods, data sets, and possible analyses. Ultimately, in Phase II of the study, the data collection and analysis phase, Phase I methodologies/datasets will be employed and final

analysis methods determined to assess whether correlations exist between respiratory complaints and prescribed/wildfire smoke.

According to a literature review conducted by Fowler (2003), studies conducted on the health effects of biomass smoke reveal ambiguous results. On one hand, findings demonstrate biomass smoke is harmful (Grant 1988), while similar studies showed no significant adverse health effects (Van Lear and Waldrop 1989; McMahon 1999). Moreover, there are researchers that argue there are minimal health risks associated with biomass smoke because defined and acceptable measures rarely exceed limits set by governmental agencies (McMahon 1999). Conversely, researchers insist there are serious implications to public health, regardless of thresholds that are below governmental agencies' requirements (Schwartz 1993; EPA 1998).

Accordingly, national information does not identify prescribed fire as a cause of exceeding Arizona Department of Environmental Quality thresholds (cited in Sandberg et al. (2002): EPA 1992); a correlation does not exist of particulate emission from total acres burned and non-attainment of local air sheds. Considering these results, it is surmised that successful smoke management programs have reduced emission in local air sheds where monitors are located (ibid). However, Sandberg and Dost (1990) stress that although there is a low probability of public health risks, an urgency for further research remains, "We urge the forest management community to consider health risks from exposure to prescribed fire smoke as our highest priority air quality issue."

In the end, as prescribed fires are conducted across the landscape and become more common, smoke management concerns will dissipate over time, due to lessened volumes of smoke generated from continued decreases of available forest fuel and generally less intense fires (Viers 2005).

## **Recommendations for Phase II**

### **Health Effects Data**

Based on information collected from health professionals and the literature review, recommendations for Phase II include:

- ❖ North Country Health Care Center staff submitted a preliminary list of primary health care providers in Flagstaff. Verify this list as exhaustive, and use to contact primary health care providers to seek participation in the study. In addition, include Flagstaff Medical Center emergency room and hospital admission and walk-in clinics' data.
- ❖ Disease surveillance can be accomplished through using the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) coded health information (CDC 2003).
- ❖ Using the most common ICD-9-CM codes across studies contained in the literature review, determine which of the codes reflect the most frequently used codes in the Flagstaff area.

- ❖ Submit the predefined list of ICD-9-CM codes to health care providers to create database of respiratory disease rates for years 2005-2007.
- ❖ In reporting disease frequencies, instruct participants to limit one diagnostic code per patient per day, or analyze each diagnostic code separately.
- ❖ To increase the validity of the study, define clear reference periods that parallel the temporal variation of fire occurrences as well as including at least two reference periods (Lipsett et al.1994; CDC 2008; Delfino et al. 2008).
- ❖ As suggested by Moore et al. (2006), analyzing historical data could illustrate seasonal variations of other sources of PM.
- ❖ To eliminate respiratory spikes more commonly observed in the winter months, conduct a separate analysis of the summer months (Moore et al. 2006).
- ❖ Generic demographic data of the study set (gender, age, etc.) as well as county health data provide by Arizona Department of Health Services, can be compared to that of the study areas' population to assess whether this data set represents the study population.
- ❖ Include patient's zip codes so those that live outside of the study area can be eliminated (Tham et al. 2009).
- ❖ Final analysis that includes ratios to compare the prescribed/wildfire fire occurrences with the reference periods, length of lag periods, as well as the specific statistical tests should be finalized after consulting a statistician.

### **Fire Occurrence Data**

- ❖ Excluding the Arizona State Forestry Division of the State Land Department, all prescribed fire and wildfire data sets have been provided and are available for the analysis of the study.

### **Arizona Department of Environmental Quality (ADEQ) Air Quality Monitors/Quantitative Models**

Based on information collected from ADEQ and the literature review, recommendations for Phase II include:

- ❖ In assessing the regulated and measured pollutants in wood smoke, fine particulates (PM<sub>2.5</sub>) have proved to be the most accurate and reliable metric in measuring exposure as well as the most elevated and sensitive to existing air quality standards measurements (Naehler et al. 2007; Delfino et al. 2008).

- ❖ Although air quality monitors have limitations, these measurements are the only empirical data available to measure PM. Using the six-day readings provided in this report will more accurately reflect PM variations as they are compared to prescribed/wildfire dates.
- ❖ Quantitative computer models could be used to assess the amount of PM emitted during fire events.
- ❖ A combination of air quality monitor data and computer modeling could be used to quantitatively assess PM levels during fire events. As an example, use air quality monitoring data for fires downwind from the monitor (determined by location-township and range) and, when fires are upwind, determine effects from the computer model.
- ❖ Other atmospheric conditions that may exist at the same time of year, that include dust, automobile and fireplace emissions, allergens, etc., will confound an explicit determination that health impacts are caused from prescribed fire smoke alone; therefore, these extraneous variables should be considered in the analysis.
- ❖ Include a review of current Emission Reduction Techniques (ERT) and Smoke Management Techniques (SMT) of land management agencies in the Flagstaff area.

## **Introduction and Purpose**

In the Southwestern ponderosa pine ecosystem, frequent low-intensity fire is an effective catalyst to promote decomposition, regeneration, diversification of species and, most importantly in this region, fire acts as an inhibitor of intense stand-replacing conflagrations (Dahms et al. 1997). Considering present day conditions, the greatest impact on the fire regimes in the Southwest have been mitigated by the suppression of frequent fire rather than its ignition. This began with Euro-American settlement that brought forth the introduction of grazing animals, high-grade logging of old growth seed trees and, beginning in the early 1900s, a paradigm shift toward complete fire suppression (Pyne 1982). Keeping the grasses in check, cyclically reproducing, would not allow the invasion of woody shrubs and an overgrowth of trees. This, in effect, protected the forests and its inhabitants, as most fires would remain tame, burning only the fuels on the forest floor. The overgrazing of grasses introduced the invasion of woody shrubs and trees that choked the historic surface fire regime of the area. Removal of old growth trees eliminated the seed source for the next generation of saplings. The abrupt evolution of the ponderosa pine ecosystem, along with fire suppression created an unhealthy forest, altering the carrying capacity from an average of 8-51 trees per acre (cited in Allen et al. (2002): Woolsey 1911) to hundreds and sometimes reaching in the thousands of trees per acre (cited in Allen et al. (2002): Allen 1998). The successive nature of the forest created not only an unhealthy forest, but also an ecosystem that threatened communities that are surrounded by the largest contiguous ponderosa pine forest in the world.

Due to the historical progression that created unhealthy and dangerous forests in the Southwest, land managers focused on managing the forests towards a healthy state; one that mimicked pre-settlement conditions, allowing the reintroduction of low intensity fire that would ultimately maintain the natural integrity of this ecosystem. To accomplish this goal, managers have both thinned the forest of inordinate, spindly trees as well as used prescribed fire to reduce excessive fuels on the forest floor. Prescribed fire is used to mimic the natural surface fire regime as it maintains acceptable fuel levels within the forest, ultimately reducing the risk of large, intense wildfires (Viers 2005). In considering smoke as a byproduct of prescribed fire, the advantages versus the disadvantages must be weighed as well as the alternative, wildfire and the subsequent amount of smoke emitted. Relative size and intensity of wildfires alone have resulted in greater amounts of particulates and other pollutants when compared to prescribed fires that produce less smoke, particulate matter and other pollutants (ibid). Supporting this, a recent study suggests that the use of prescribed fires have slashed fire carbon emissions by 18 to 25 percent in 11 Western states during the years of 2001-2008 (Wiedinmyer et al. 2010). Regardless, challenges to land managers remain and the benefits of utilizing prescribed fire as a management tool are not fully recognized until a wildfire has occurred and its intensity is defined by the preceding land management practices in the area (Viers 2005). To further exemplify this point, Fowler (2003) explains,

The predominant view of fire ecologists and forest managers is that prescribed burning reduces long-term net health costs by reducing the risks of catastrophic wildfires that could result in even greater levels of air pollution and have other injurious effects. Fire ecologists promote prescribed burning as a technique for enhancing ecosystem health in

fire-adapted areas that rely on periodic burnings. Many fire ecologists also promote a “let it burn” policy for wildfires arguing against the expensive policies designed to suppress or eliminate unplanned wildland fires. In this view, fire is regarded as beneficial for long-term ecosystem health and human health.

There are several land management agencies in the Flagstaff area that manage the forest with prescribed fire. In doing so, there are multiple challenges and considerations in smoke management that includes fuel loading, nearby residents, timing of burns (season), cost, variable wind patterns and others (P. Summerfelt, Flagstaff Fire Department (FFD), personal communication). In most cases, shifting patterns in wind promote favorable smoke dispersion; however, unexpected wind shifts can cause smoke to penetrate residential areas. These unexpected air movement shifts have caused prescribed fire smoke to infiltrated areas in and around Flagstaff to levels that are noticeable by residents. Although a sector of the population has reservations towards prescribed fires and their emissions, a survey conducted by the Social Research Laboratory in 2006 showed the majority of the population supports its use (SRL 2006). However, for more susceptible populations who are at risk for health complications when exposed to smoke (elderly, young children, or those with pulmonary or cardiovascular ailments and smokers) (Fowler 2003; Lipsett et al. 2008), this group is apprehensive about the possible effects. Correspondingly, many health care practitioners in Flagstaff are also interested in the issue (R. Swanson, North Country Health Care Center (NCHCC), personal communication). However, there is only anecdotal evidence that prescribe fire smoke has a negative impact on the health of the citizens in Flagstaff. It is the intent of this study, initiated by the Greater Flagstaff Forests Partnership (GFFP), to assess these effects with a study design that includes quantitative data analysis resulting in a more definitive causal relationship to assess whether, or not, smoke from prescribed fire has adverse effects on health of the citizens of Flagstaff.

To quantify health effects of prescribed and wildfire fire smoke, the study is delineated in two phases. In the first phase of the study, Phase I, a study design/methodology will be determined through a literature review and by exploring the issue with professionals in the health field, various land management agencies and agency reports. The study design includes three main data collection elements for years 2005 through 2007, which represent both wet and dry precipitation years (2005 - wet, 2006 and 2007 - dry). The three data sets include: 1. health reports of respiratory complaints predetermined by specific, preselected billing codes that represent general respiratory complaints; 2. prescribed fire and wildfire dates, location and burn types and; 3. Arizona Department of Environmental Quality (ADEQ) reports.

Due to the variability of climatic factors and the difficulty in comparing these amongst each prescribed burns’ specific objectives, weather variables such as, precipitation, wind speed and direction, temperature, etc., will not be included in the recommended methodology (see Appendix **xx** for supplemental preliminary weather data information).

The goal of Phase I of the study is to develop a workable methodology that includes data collection methods, data sets, and possible analyses. Ultimately, in Phase II of the study, the data collection and analysis phase, Phase I methodologies will be employed and final analysis

methods determined to assess whether correlations exist between respiratory complaints and prescribed/wildfire smoke.

## **Literature Review**

Members of GFFP's Board of Directors outlined an initial study design For Phase I. The goal was to develop a methodology that would assess whether prescribed fire smoke had noticeable health effects on Flagstaff residents. To assess this association, health data that includes emergency room and primary care physician visits would be compared to fire occurrence data (prescribed and wildfire) and ADEQ air quality monitoring reports. To further assess whether the methodology and variables selected were valid and reliable, a review of recent literature of similar studies was initiated to determine whether the preliminary study design and methodology could be improved.

The literature search process was initiated with the United States Forest Service (USFS) Rocky Mountain Research Station (RMRS) using the following search topics: 1. Health reports of respiratory complaints (2005-2007) – predetermined by specific billing codes, provided by an established primary care provider in Flagstaff, AZ; 2. Prescribed fire & wildfire dates (2005-2007) and; 3. ADEQ reports (2005-2007). This search resulted in 51 abstracts of papers/articles that matched key word submissions (see Appendix **xx**). In addition, the RMRS results yielded 26 reports, accessible through various agency websites, which support data collection efforts (see Appendix **xx**). Once the abstracts were reviewed, 26 of the 51 papers/articles indicated further review for information that is relevant for this study.

Currently, there are a limited number of studies directly evaluating the health effects of air pollution resulting from the burning of biomass (Naeher et al. 2007), and even less when effects are correlated with prescribed fires (Sandberg and Dost 1990; Viers 2005). Most of the studies examined in this literature review were based on health effects during intense forest, grass or brush fire events.

In a comprehensive literature review conducted by Naeher et al. (2007), the epidemiological studies of health effects when exposed to biomass smoke (wildfire events) generally show a consistent relationship between exposure and increased respiratory symptoms, including hospital admissions and emergency room visits. In addition, several studies suggest that asthmatics are a particularly susceptible sub-population when exposed to smoke. However, since the majority of the studies have concentrated on respiratory health outcomes versus cardiovascular effects, this revealed there is insufficient data to assess the extent to which ambient wood smoke pollution might affect the circulatory system (Naeher et al. 2007; Delfino et al. 2008).

According to a literature review conducted by Fowler (2003), studies conducted on the health effects of biomass smoke reveal ambiguous results. On one hand, findings demonstrate biomass smoke is harmful (Grant 1988), while similar studies showed no significant adverse health effects (Van Lear and Waldrop 1989; McMahon 1999). Moreover, there are researchers that argue there are minimal health risks associated with biomass smoke because defined and acceptable measures rarely exceed limits set by governmental agencies (McMahon 1999).

Conversely, researchers insist there are serious implications to public health, regardless of thresholds that are below governmental agencies' requirements (Schwartz 1993; EPA 1998).

Additional information obtained in the literature review will be discussed as it pertains to each section of this report: Health Effects Data, Fire Occurrence Data and Air Quality/Monitoring Data.

## **Health Effects Data**

### **Literature Review**

#### **ICD-9-CM Codes**

Disease surveillance can be accomplished through using the *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) coded health information from physician visits and emergency department/hospitalization admissions (CDC 2003). This classification system can be used directly as it is reported during a health visit, or by matching the code with analysis of text in various reporting systems such as emergency department logs, 911 calls, or nurse call-in line data (ibid). The ICD-9-CM codes were designed for diagnosis and procedures associated with hospitalizations; however, they are also used for insurance reporting (ibid; M. Murnane, Business Office Manager, NCHCC, personal communication). These codes are readily available for use in health care systems in multiple settings (outpatient, inpatient, emergency rooms, physician's offices, etc.) and are often available electronically, thus the codes can be easily shared and compared between systems (CDC 2003).

During a study initiated by the Center for Disease Control (CDC) (CDC 2003), a multi-agency workgroup was established and developed 11 syndrome groups based on an exhaustive search through all ICD-9-CM codes. Once codes for the respiratory syndrome were delineated (see Appendix xx), definitions for the respiratory syndrome group were compiled (see Appendix xx). Once this definition was finalized, codes were developed from the sub-syndrome group (see Appendix xx).

Accordingly, a recent CDC study (2008) included the respiratory syndrome and five respiratory sub-syndromes (asthma, bronchitis, chest pain, cough, and dyspnea). In studies conducted by Mott et al. (2002), Lipsett et al. (2004), Moore et al. (2004), and Delfino et al. (2008), ICD-9-CM diagnostic codes were also used to quantify emergency room visits and hospitalization admissions. The Arizona Department of Health Services (AZDHS) provides a primary listing of ICD-9-CM codes used for emergency room and hospitalizations in Arizona (AZDHS 2010) (Appendix xx contains a summary table of ICD-9-CM codes used across organizations and studies). Accordingly, ICD-9-CM codes used most frequently across studies (not mutually exclusive) include: 493 (asthma); 466, 496, 490-492 (bronchitis); 460-465 (upper respiratory conditions); 460-519 (respiratory) and; 480-487 (pneumonia). Considering studies evaluated effects from intense conflagrations, several studies included mental illness to eliminate possible psychological effects verses actual physical diagnoses (Lipsett et al.

1994; Moore et al. 2006; Naeher et al. 2007). Ultimately, the CDC (2003) recommends codes selected for a particular disease surveillance program should be based on the data sources that are available and prevalent code usage and frequency in the study area.

Similarly, in a literature review conducted by Fowler (2003), the most common cardiopulmonary complaints resulting from biomass smoke included: decline in lung function, decline in breathing rate, breathing discomfort, emphysema, asthma, allergies, bronchitis, angina, myocardial infarction/heart attack, and pneumonia; however, ICD-9-CM codes were not referenced (Cited in Fowler 2003: Kane and Alarie 1977; Betchley et al. 1997; Patz et al. 2000; Tab et al. 2000).

Limitations in using ICD-9-CM codes include misclassifications due to subjective patient-reported primary complaints and the subsequent diagnosis codes assigned and/or general coding errors (Moore et al. 2006; CDC 2008). Moreover, consideration that the patient might have been classified as showing more than one disease indicator on a given visit should be addressed by limiting the count to one diagnostic code per patient per day or by analyzing each diagnostic code separately (Roberts and Corkill 1998; CDC 2008). Other typical limitations of emergency room/hospitalization analyses relate to economic factors such as access to other health care providers (primary health care physicians) and those that are underreported due to lack of health insurance (Roberts and Corkill 1998; Naeher et al. 2007). This premise was also highlighted in a study conducted by Lipsett and Waller et al. (1994) and Smith et al. (1996; cited in Naeher et al. 2007), stating hospital-based surveys can underestimate disease rates among populations as mild illnesses are not reported or the affected population used alternative (other than emergency rooms and hospitals) health care facilities.

## **Lag Period**

Lag of emergency room visits to increases in particulate matter (PM) were observed in several studies that included one day (Cited in Fowler 2003: Schwartz 1994), two days (Delfino et al. 2008), five days (Johnston et al. 2002), two weeks (Mott et al. 2002), to as much as five weeks (Moore et al. 2006). These results suggest the respiratory ailments took days to several weeks to develop and/or patients tried to manage their symptoms on their own before seeing a physician (Moore et al. 2006).

## **Analysis**

### Reference Periods

To control for temporal variation of fire occurrences, remote and recent reference periods should parallel the fire period by selecting the same day of week, weekdays and/or weekends (Lipsett et al. 1994; CDC 2008; Delfino et al. 2008). In addition, to strengthen data analysis and conclusions, several reference periods should be used. For example, Smith et al. (1996) and Sorenson et al. (1999) methodologies included only one reference period which, according to Naeher et al. (2007), could limit the findings' relevance and may not provide a stable basis for comparison.

In a study conducted by Moore et al. (2006), they suggest assessing seasonal variation in other sources for PM by analyzing historical air quality data. Similarly, respiratory spikes are not common during the summer months; therefore, focusing on summer months may assist in controlling for abrupt respiratory increases, most commonly observed during the winter (ibid). In addition, other studies suggest comparing findings to national disease data and/or develop demographic tags such as identification of smokers or by comparing demographic data of the respondents in the data set to the demographics of the area of study (Roberts and Corkill 1998). Tham et al. (2009) suggest verifying the population resides in the area of study by obtaining and verifying the current zip codes.

Nonfederal hospitals in Arizona are required to submit uniform patient reports to the Arizona Department of Health Services every six months (AZDHS 2010). Information is available on AZDHS website that includes both hospital inpatient discharges and emergency room visits. Annual reports by county are available that include tracking diseases of the respiratory system (acute bronchitis and bronchiolitis, pneumonia, chronic bronchitis and asthma) (AZDHS 2010). These data could be used to compare disease rate incidents for the County with those obtained in the study.

#### Calculation of Emergency Room and Hospital Visits

Several studies used a type of ratio proportions of diagnostic categories to compare the fire period to reference periods. For example, in a study conducted by Lipsett et al. (1994), ratios of proportions of specific diagnostic categories, comparing the fire week to the two reference weeks, were calculated using the following formula:

$$\frac{\text{Number of visits for the diagnosis/total visits during the fire period}}{\text{Number of visits for the diagnosis/total visits during the reference periods}}$$

Similarly, in a study conducted by the CDC (2008), the number of visits for a given indicator per day were normalized by dividing by the mean number of visits for the indicator per day during both periods combined in the pre-fire versus fire period. Duclos et al. (1990) calculated observed-to-expected ratios of ER visits, based on the numbers of visits during two reference periods.

Generally, limitations to examining emergency room/hospitalizations/physician visits during biomass smoke events are based on the assumption that all patients had equal exposure to smoke; where, in reality, there are most likely gradients of exposure (Moore et al. 2006).

#### Statistical Analyses

The majority of the studies conducted a time series analysis (Jacobs et al. 1997; Emmanuel 2000; Johnston et al. 2002; Mott et al. 2005; Delfino et al. 2008). Various statistical analyses were conducted that include: 1) Poisson regression analysis (Duclos et al. 1990; Delfino et al. 2008; Tham et al. 2009); 2) Epidemic curve (Lipsett et al. 1994); 3) Nonparametric Kruskal-Wallis test (CDC 2008); 4) Chi-square tests/Gart and Nam.20 (Lipsett et al. 1994); 5) logistic regression analyses (Smith et al. 1996; Mott et al. 2002) and; 6) ANOVA (Sutherland et al. 2005).

## Institutional Review Board

When collecting information on human subjects, an Institutional Review Board (IRB) should complete a review of the proposed project. These reviews protect the rights of human subjects when used in research and prevent unethical treatment during the process (IRB NAU 2010). Currently, for Phase I of this study, an IRB application has not been submitted. As secondary health data will be collected in Phase II, an application should to be submitted. However, since the secondary data required for the study will be limited to frequency of a specific health ailment, with patient’s identifying information omitted, the IRB application will most likely be exempt from review.

## Primary Health Care Provider Data

A primary health care provider that serves approximately one in four citizens in the greater Flagstaff area (R. Swanson, NCHCC, personal communication), NCHCC agreed to participate and serve as a pretest participant in the study. Contact was initiated (prior to completion of the literature review) to allow for assistance in developing a workable methodology for extraction of health care data. Initially, a sample database that contained frequency of respiratory complaints and the corresponding costs of these visits was extracted on a daily basis for 2005. To protect patient confidentiality and anonymity, all identifying information, such as patient names and addresses, were omitted from the data sets. To determine exact variables for health effects, NCHCC’s billing specialists were consulted and a list of eight ICD-9-CM billing codes for general respiratory ailments was developed (see Table xx).

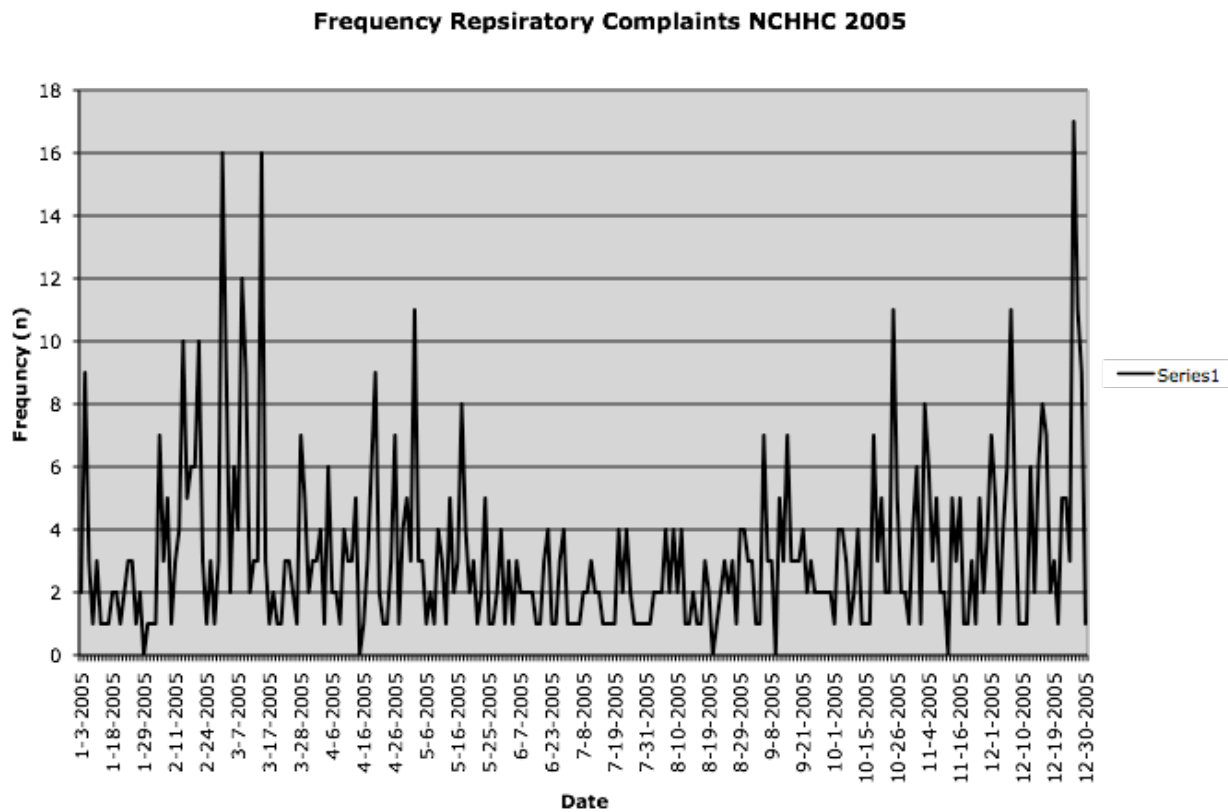
Table xx. North Country Health Care Center ICD-9-CM Codes	
ICD-9-CM Code	ICD-9-CM Description
786.09	Respiratory distress
518.81	Acute respiratory failure
786.07	Wheezing
786.9	Respiratory system NEC
786.05	Shortness of Breath
786.2	Cough
466	Acute Bronchitis
493.02	Acute extrinsic asthma with exacerbation

Source: NCHCC 2009

The intent of the exercise with NCHHC was to develop a workable methodology that could be employed by other primary health care providers in Flagstaff. For Phase II of the study, the data collection phase, this information would provide the variables identified (e.g. frequency of selected ICD-9-CM codes for years 2005, 2006 and 2007, zip code, gender, age, etc.) as well as providing a model data set. This would not only provide clarification of the exact information that is required for other health care providers, but also would increase the likelihood of participation due to clear and concise requirements of the required variables and their format.

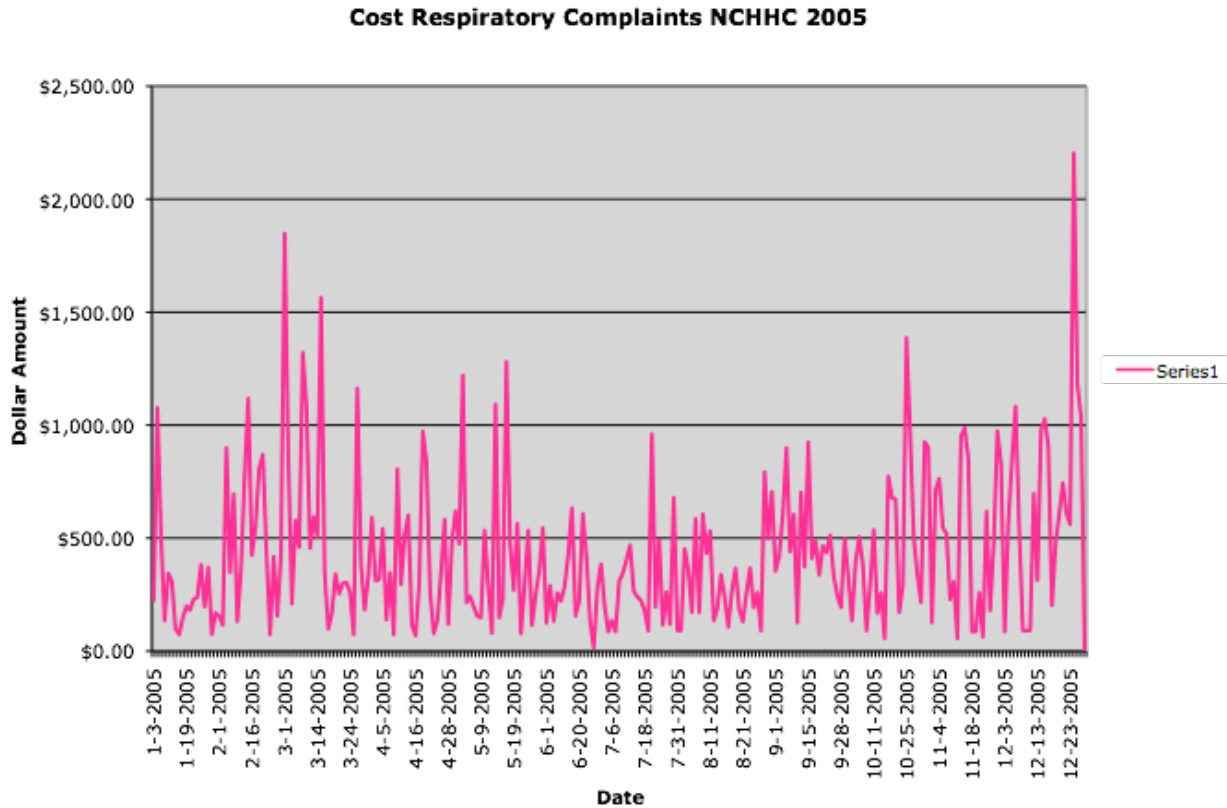
NCHHC billing specialist applied these codes to their database of patient visits in 2005 by patient frequency of visits as well as the costs of the patient visits (see Appendix xx). Although cost of the visit was not a variable required for the study, NCHHC provided this information. However, these data were not limited to one diagnostic code per patient per day. In addition, total costs of visits were reported as a daily total. To illustrate trends in frequency of complaints and costs of patient visits on a daily basis in 2005, preliminary results are depicted in Figure xx and xx respectively.

Figure xx. Frequency of Respiratory Complaints NCHCC 2005



Source: NCHCC 2009

Figure xx. Daily Cost of Respiratory Complaints NCHCC 2005



Source: NCHCC 2009

NCHCC staff submitted a preliminary list of primary health care providers in Flagstaff (see Appendix xx). For Phase II, the data collection phase, this list of primary health care providers should be verified as exhaustive, containing all primary health care providers in Flagstaff. Once an exhaustive list is formulated, providers can be approached to determine their willingness to participate in the study as well as their ability to provide archival data of the determined billing codes for years 2005 through 2007.

## Fire Occurrence Data

Both wildfire and prescribed fire data by date, type and size (acres) for years 2005 through 2007 were required for the study. After consulting the USFS Deputy Fire Staff Officer (R. Coop, Coconino National Forest (COF), personal communication), three primary prescribed fire ignition sources were identified that include: 1. FFD, 2. USFS and, 3. The Arizona State Forestry Division (ASF). In addition, to account for other significant sources of ambient wood biomass smoke, wildfire data was obtained from the USFS and ASF.

## **Prescribed Fire Data**

According to ADEQ's permit classification website, Class I permits are issued to any source that meets the requirements of Arizona Administrative Code (A.A.C.) Title 18, Chapter 2, Article 302(B)(1) (ADEQ 2009). Class I permits are described as a "major source" of emissions and are required from federal or state land managers that emit 100 tons per year of any "criteria air pollutant" (ibid) which are carbon monoxide (CO), ozone, nitrogen dioxide, sulfur dioxide, lead, particulate matter 10 microns in size and smaller (PM<sub>10</sub>), and particulate matter 2.5 microns in size and smaller (PM<sub>2.5</sub>) (ADEQ 2006).

Prescribed Burn Accomplishment; Wildfire Reporting requirements are described in Article 15: Forest and Range Management Burns Title 18: Environmental Quality, Chapter 2 Air Pollution, R18-2-1507 (Section A) (ADS 2005-2009). Federal or state land managers that meet the Class I criteria are required to submit a "Burn Accomplishment" form to ADEQ by 2:00 p.m. the next business day following the burn (ibid). Information required on this form stipulates four main components that include: 1. Conditions or circumstances that could impact the daily burn decision process; 2. The date, location, fuel type, fuel loading, and acreage burned, 3. The Emission Reduction Techniques (ERT) ("methods for controlling emissions from prescribed fires to minimize the amount of emission output per unit of area burned") and; 4. Smoke management techniques (SMT) ("management and dispersion practices used during a prescribed burn or wildland fire use incident which affect the direction, duration, height, or density of smoke") (ibid). In addition, managers should include any further ERTs and SMTs that they used to reduce emissions or manage the smoke from the burn (ibid).

As mandated in Article 15, ADEQ is required to "maintain a record of burn requests, burn approvals/conditional approvals/denials and accomplishments for 5 years" and in R18-2-1511 Monitoring, (Section E) "Federal/State Land Manager shall keep on file for one year following the burn date any monitoring information required under this section" (see Appendix **xx**) (ADEQ 2009). Given that ADEQ is required to keep burn accomplishments for five years, the study's requirement to obtain data for years 2005, 2006 and 2007 could be met.

The ADEQ was contacted to provide prescribed burn accomplishments and wildfire reports from federal and state land managers for the years 2005 through 2007. To delineate the exact study area in question, ADEQ was provided the following description provided by the GFFP's Board of Directors (BOD), denoting the greater Flagstaff area:

Legal boundaries: From Township 19 North, Range 5 East, east to Township 19 North, Range 9 East, then north to Township 23 North, Range 9 East, then west to Township 23 North, Range 5 East, then south to starting point.

ADEQ has archival electronic files that include the burn names, acres and fuel information; however, the locations of these fires are not identified. Therefore, these data are maintained as statistical summaries that reflect prescribed fires over the entire state (R. Coop, Deputy Fire Staff Officer, COF, personal communication). If needed, specific information with the burn's

location could be extracted from hard copies of the burn accomplishments, but this information is not available in electronic format.

As prescribed fires ignited by FFD are either within city boundaries or associated contract service areas outside of city limits (not classified as state or federal lands), prescribed fire occurrence data for the City of Flagstaff was obtain directly from FFD's Fire Management Officer (P. Summerfelt, FFD, personal communication) (see Appendix xx). This data included the date, fire type: broadcast or pile burn, smoke observations, public comment and comments from the fire officer. Burn size was described in either acres or number of piles. Although FFD does not emit 100 tons per year of criteria air pollutants, they voluntarily participate in the permitting and tracking process with ADEQ (ibid).

In addition, FFD provided estimates of prescribed fire emissions in 2004 and 2005 based on a Simple Approach Smoke Estimation Model (see Table xx) (for FFD's original table and graphic depiction, see Appendix xx). Considering total acres burned in 2004 and 2005, total PM<sub>2.5</sub> emissions when broadcast and pile burned were approximately .017 and .071 tons per acre respectively. As emissions from broadcast and pile burns are averaged (.044 tons per acre) and compared to emissions from wildfire at .234 tons per acre, this represents an approximate increase of PM<sub>2.5</sub> emissions that are five times greater from wildfires when compared to prescribed fires.

Table xx. Prescribed Fire Emissions - City of Flagstaff Fire Department					
Year	2004				
	Broadcast	Piled	Broadcast	Piled	Wildfire *
	Acres				
TSP Total Emissions (Tons)	183	515	5.395	60.931	163.620
Total PM <sub>2.5</sub> Emissions (Tons)			3.024	36.812	100.129
Total PM <sub>2.5</sub> Emissions (Tons/Acre)			0.017	0.071	0.234
Total Fuel Consumed (T/A)			3.516	.441	20.473
Year	2005				
	Broadcast	Piled	Broadcast	Piled	Wildfire *
	Acres				
TSP Total Emissions (Tons)	262	66	7.724	7.809	76.887
Total PM <sub>2.5</sub> Emissions (Tons)			4.330	4.718	47.052
Total PM <sub>2.5</sub> Emissions (Tons/Acre)			0.017	0.07	0.234
Total Fuel Consumed (T/A)			3.516	.441	20.473

SP - Total Suspended Particulates

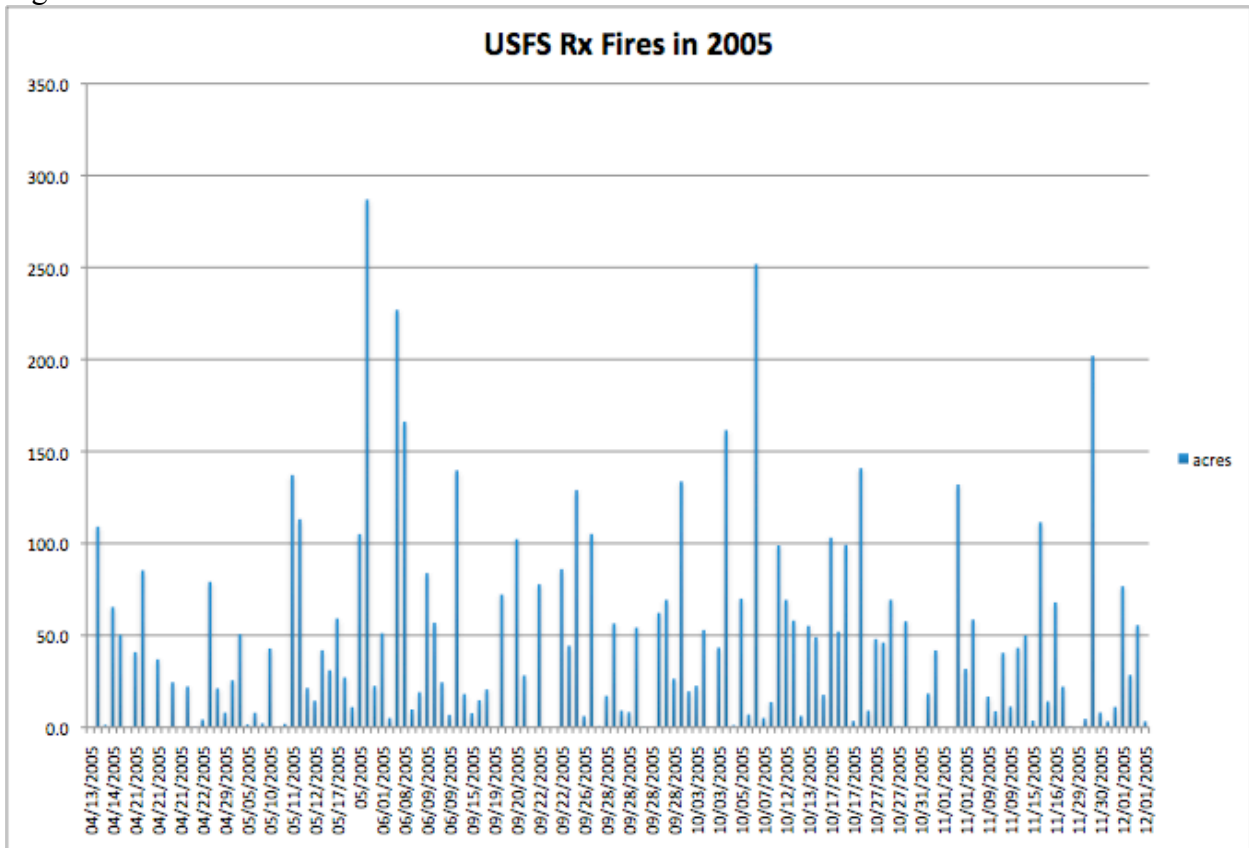
PM<sub>2.5</sub> - particulates less than 2.5 microns in diameter (concern to health)

Wildfire emissions of comparable size as total acres (broadcast+piled)

Source: Flagstaff Fire Department (2008)

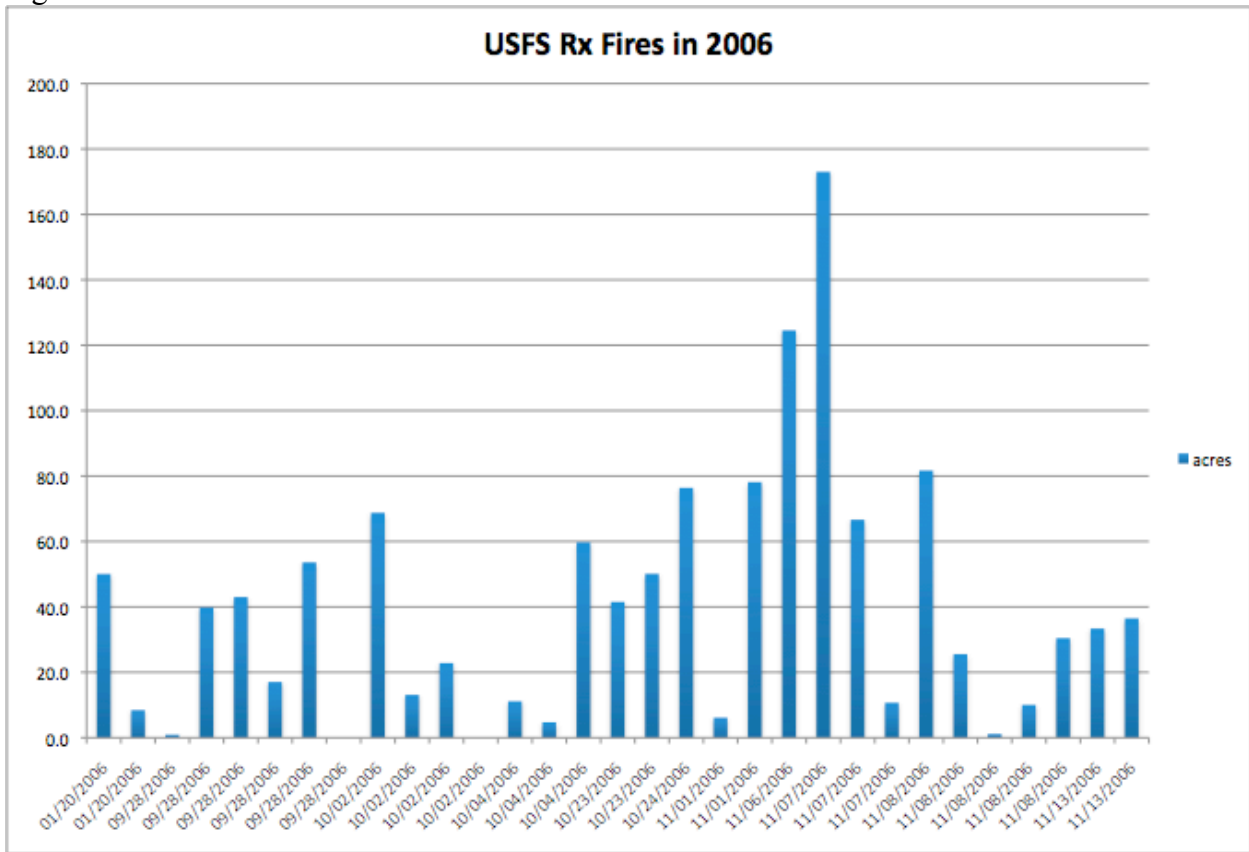
Prescribed fire data were obtained from the USFS Administrative Specialist located at the COF Supervisor's Office. Data included the date, project name, size (acres) and location (block #, township, range, section) (see Appendix xx). Within the database, all records were described as "Rx fire-Broadcast-first entry burns." In total 183 prescribed fires occurred in years 2005-2007. Proportionally, the frequency of burns was much greater in 2005 (n=142; 78%) as compared to 2006 (n=31; 17%) and 2007 (n=10; 5%) (see Figures xx-xx). Increased frequency of prescribed fires in 2005 could be related to a noticeably wet year.

Figure xx. USFS Prescribed Fires in 2005



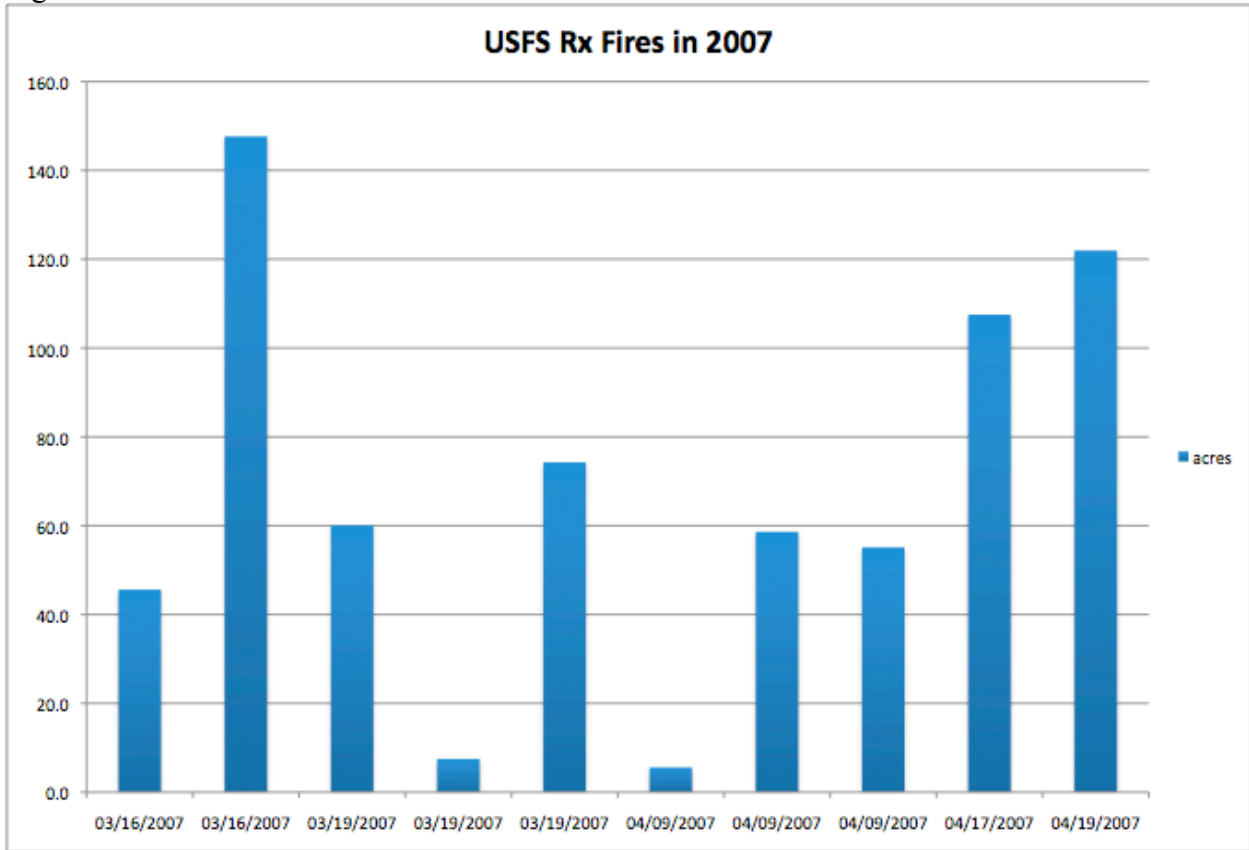
Source: USFS 2010

Figure xx. USFS Prescribed Fires in 2006



Source: USFS 2010

Figure xx. USFS Prescribed Fires in 2007



Source: USFS 2010

Generally, the ASF does not conduct prescribed fires on state lands in and around the Flagstaff area and it was reported there were no prescribed fires on state lands in the area of study between the years 2005-2007 (K. Pajkos, ASF, personal communication).

## Wildfire Data

The wildfire reporting required by ADEQ R18-2-1507, Section D mandates federal and state land managers to report wildfire incidents that burned more than 100 acres per day in timber or slash fuels or 300 acres per day in brush or grass fuels no later than the following business day after the incident (ADS 2005-2009). In addition, for each day the fire burns, managers are required to report the wildfire's location, the predominant fuel type, an estimate of the quantity consumed, and an estimate of the area charred that day (ibid).

For all wildfires on the COF, that includes fires less than 100 acres, data were obtained directly from the Resource Information Specialist on the COF (Peaks and Mormon Lake Ranger Districts) and **The ASF** (see Appendix **xx**). The identical legal boundaries given to ADEQ were used to delineate the study area for USFS. The data provided by the USFS included the fire name, date, reported size (acres), and location described by township, range, section and quarter section (see Appendix **xx**). In the USFS database, in 2005, there were 148 total wildfires with the largest fire reported as the Wedding fire (80 acres). During this year,

the majority of fires were very small, under one acre in size. In 2006, a total of 161 fires occurred, with the largest fire reported as the Knife fire (560 acres) and this was followed in size by a much smaller fire that year, 15.3 acres that burned at Bismark Lake. The majority of wildfires in 2006 were also less than one acre in size. In 2007, a total of 175 wildfires burned in the area of study with the Monkey fire reported as largest (65 acres) fire that year. This was followed in size by the Money fire (28 acres) and the Wing fire (25 acres). In total there were six fires 10 acres or more; however, as in 2005 and 2006, most fires were less than one acre in size.

For years 2005-2007, maps for wildfires greater than 100 acres for the state of Arizona were obtained from the Southwest Coordination Center (SWCC) Predictive Services' Historical Fires and Acres section of their website (see Appendix xx) (SWCC 2009). According to these maps, depicting wildfires in the vicinity of Flagstaff that were 100 acres or more, the Tank Fire (USFS, 121 acres) occurred in 2005; in 2006 three fires were at least 100 acres that include, the Woody (ASF, 100 acres), Brins (USFS, 4317 acres), and La Barranca (ASF, 836 acres) and; in 2007, the Bargaman fire (USFS, 320 acres). For all wildland fires in Arizona, including those under 100 acres, only one map was available for the year of 2007 (SWCC 2009) (see Appendix xx). Although these maps do not correlate with the exact description of the study area, described in township and range, these are yet another source of data in regards to historical wildfire.

## **Air Quality/Monitoring Data**

### **Literature Review**

#### **Particulate Matter**

Smoke is a composite of carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen and trace minerals (Lipsett 2008). Of the pollutants associated with smoke, particulate matter is the primary concern for short-term (hours or weeks) health effects (ibid) and is the air pollutant most consistently elevated (Sapkota et al. 2005). Particulate matter is measured in micrometers ( $\mu\text{m}$ ). As an example, one human hair is approximately 60  $\mu\text{m}$  (Lipsett 2008). Particulate matter larger than 10  $\mu\text{m}$  does not usually penetrate the lungs. However, particulates 10  $\mu\text{m}$  or less can be inhaled into the lungs, while exposure to the smallest particles can have the greatest effects on the lungs and heart. Particulate matter 10  $\mu\text{m}$  or smaller are referred to as  $\text{PM}_{10}$  or "coarse particles," while those equal to or smaller than 2.5 micrometers are referred to as "fine particles" or  $\text{PM}_{2.5}$  (ibid). Coarse particles do not travel far and consist of mostly soil and ash, while fine particles can travel long distances (Roberts et al. 1998; Naeher et al. 2006; Lipsett et al. 2008). Particles from smoke are generally smaller than 1  $\mu\text{m}$  and peak in size distribution from 0.15 and 0.4  $\mu\text{m}$  (Kleeman et al. 1999; Hays et al. 2002). In assessing the regulated and measured pollutants in wood smoke, fine particulates ( $\text{PM}_{2.5}$ ) have proved to be the most accurate and reliable metric in measuring exposure as well as the most elevated and sensitive to existing air quality standards measurements (Naeher et al. 2007; Delfino et al. 2008). Most studies included in the literature review measured  $\text{PM}_{2.5}$  and/or  $\text{PM}_{10}$ , relying on data collected from

available air quality monitors. However, several studies did not include air quality measurements as they were unavailable or not a component in the study design.

### **Air Quality Monitors/Quantitative Models**

Available air quality monitors that measure particulate matter do not reliably characterize smoke exposure to populations, which is a general limitation of all biomass fire studies (Naeher et al. 2007). This is especially true when the monitors are located upwind from the fire, which will most likely indicate the populations affected were exposed to higher PM<sub>2.5</sub>/PM<sub>10</sub> and smoke concentrations than reported (Chen et al. 2006; Naeher et al. 2007). Conversely, if monitors are located downwind of the fire, monitor readings are more likely to reflect accurate PM concentrations.

Many studies dispute using 24-hour averages due to peaks in smoke penetration/PM levels during fire events. Considering fire behavior, PM levels of smoke may peak above standards for a few hours before it disperses, but may not show as a violation in the 24-hour reading (Roberts and Corkill 1998; Sandberg et al. 2002; ADHS 2008; CDPH 2009). As a direct example, in a study conducted by Roberts and Corkill (1998), 24-hour averages were below standards; however, hourly readings showed elevated PM<sub>2.5</sub> levels (145-246 µg/m<sup>3</sup>) (ADEQ threshold 24-hour average less than or equal to 65 µg/m<sup>3</sup> over a three year time-period) (see ADEQ Annual Reports p. xx for further explanation of annual and 24-hour averages). Violations that exceed standards for a short duration could result in the possibility of smoke affecting health or minimally causing physical irritation; however, National Ambient Air Quality Standards (NAAQS) violations do not correlate with these effects (Sandberg et al. 2002). Similarly, in a study conducted by Emmanuel (2000), results support adverse health effects could occur when PM<sub>10</sub> concentrations are well below existing standards of 24-hour average less than or equal to 150 µg/m<sup>3</sup> over a three year time-period.

In addition, Sandberg et al. (2002) revealed if the State is unable to determine definitively that the cause of non-attainment is due to burning of biomass, future mitigation efforts are not employed. Furthermore, prescribed fire has not yet proved as a significant cause of exceeding NAAQS thresholds; however, as restoration efforts and increased burning is predicted into the future, this scenario is expected to change significantly (cited in Sandberg et al. 2002: USDI and USDA 1995). According to the Sandberg et al. (2002), national information does not identify prescribed fire as a cause of exceeding ADEQ thresholds (EPA 1992); a correlation does not exist of particulate emission from total acres burned and non-attainment of local airsheds. Considering these results, it is surmised that successful smoke management programs have reduced emission in local air sheds where monitors are located (ibid).

As an alternative to air quality monitoring results, quantitative models are available for a variety of primary fuel types that predict biomass consumption and emission production (Sanberg and Dost 1990). However, Sanberg and Dost (1990) point out that development and application of the emission production models are lagging and are limited. To further explain their point, an example was provided where fuel consumption during very wet burning conditions and consumption of ponderosa pine duff are poorly modeled and understood. Predictive algorithms are also available for large fuel consumption and duff consumption

during prescribed fires for the common fuel types in the Pacific Northwest (cited in Sanberg and Dost 1990: Ottmar 1983). In the end, additional research is needed to include a range of conditions where the model can be considered reliable. Another limitation in using this type of modeling is the software's interface that does not promote widespread use (ibid). As a final methodology is considered, the most current fire models will need to be explored to assess applicability to ponderosa pine forests of the Southwest and whether these models are easily accessed and contain a reasonable user interface.

## **Arizona Department of Environmental Quality Annual Reports**

ADEQ publishes annual air quality reports. These reports present information for the previous year's data (2006 report summarizes data collected in 2005). ADEQ's monitoring personnel collect air samples to determine the presence or absence of contaminants (ADEQ 2006). Particulate matter, PM<sub>10</sub> and PM<sub>2.5</sub>, is usually sampled by ADEQ for 24 hours, from midnight to midnight, every six days. Data is summarized into quarterly or annual averages (ibid).

The Environmental Protection Agency established National Ambient Air Quality Standards (NAAQS) as guidelines and thresholds that characterize air quality that could be harmful to citizen's health (ibid). Prior to 2006, the annual standard for PM<sub>10</sub> is achieved when the mean concentration is less than or equal to 50 µg/m<sup>3</sup> (micrograms per cubic meter) over a three year time-period. For the 24-hour measurements, the standard is attained when 150µg/m<sup>3</sup> is not exceeded more than once per year over a three year time span. In 2006, The EPA eliminated the annual standard for PM<sub>10</sub> but retained a 24-hour standard of 150 µg/m<sup>3</sup> or less (ibid).

Prior to 2006, the annual PM<sub>2.5</sub> standard is attained when the average of annual means over a three year period is less than or equal to 15.0 µg/m<sup>3</sup> and the 24 hour average concentration is equal to or less than 65 ug/m<sup>3</sup> (ibid). In 2006, the EPA changed the acceptable PM<sub>2.5</sub> for 24 hours from 65 ug/m<sup>3</sup> to 35 µg/m<sup>3</sup> (ibid). Beginning in 2006, compliance with the 24-hour PM<sub>2.5</sub> standard is attained when the three-year average is equal to or less than 35 µg/m<sup>3</sup>.

Currently there are 28 PM monitoring sites in Arizona (for map see Appendix **xx**). ADEQ established a monitoring site at Flagstaff Middle School in 1996 that measured PM<sub>10</sub> (see Figure **xx**). Three years later, in 1999, a PM<sub>2.5</sub> sampler was added to the site (ADEQ 2007). Both monitors earn the SLAM designation - State and Local Air Monitoring Stations. These monitors are filtered and are strictly calibrated to meet NAAQS compliance, however a range of area they cover is undeterminable as particulate matter is airborne; thus, particles filtered into the monitors could literally be identified and measured from as far as China (B. Lum, ADEQ, personal communication).

Figure xx. Flagstaff Middle School Monitoring Station



Source: ADEQ 2009

To meet the EPA minimum monitoring requirements, the *State of Arizona Air Monitoring Network Plan* (2008) added ozone monitoring to the Flagstaff Middle School site (for map see Appendix xx). ADEQ's ozone monitor began to collect data on April 1, 2008.

PM<sub>10</sub> and PM<sub>2.5</sub> data collected at the Flagstaff Middle School monitoring site (2005-2007) are shown in Table xx and xx respectively. In 2005, valid data recovery was less than 75 percent in one or more calendar quarters; therefore, a PM<sub>10</sub> three year annual and three year 24 hour average could not be calculated. However, annual average PM<sub>10</sub> values from 2005 to 2007 did not exceed the standard of 50 µg/m<sup>3</sup>. The highest annual average occurred in 2007 at 21.2 ug/m<sup>3</sup>. The 24-hour average also met the criteria and was not higher than 150 µg/m<sup>3</sup>. The highest maximum value was 56 µg/m<sup>3</sup> also in 2007. These data indicate that PM<sub>10</sub> was at very acceptable levels during the years 2005 through 2007.

<b>Table xx. PM<sub>10</sub> Data (in µg/m<sup>3</sup>) 2005-2007</b> Before 2006: NAAQS annual average < or = 50 µg/m <sup>3</sup> over a three year time-period; NAAQS 24-hour average < or = 150 µg/m <sup>3</sup> over a three year time-period *					
	Annual Average	24 Hour Average		Valid Data Recovery	
		Max Value	2nd High	No. of Obs.	%**
2005 PM <sub>10</sub> Data (in µg/m <sup>3</sup> ) ***	17	38	35	49	80
2006 PM <sub>10</sub> Data (in µg/m <sup>3</sup> )	18	37	35	59	97
2007 PM <sub>10</sub> Data (in µg/m <sup>3</sup> )	21.2	56	42	58	97

\* 2006 and later - annual average standards eliminated, 24-hour remained the same.

\*\* % of observations that are valid.

\*\*\* Indicates data does not satisfy EPA's summary criteria, usually meaning less than 75 percent valid data recovery available in one or more calendar quarters. Therefore, a three-year average was not calculated.

(Adapted from ADEQ 2006, 2007, 2008)

For the years 2005 through 2007, the three-year annual average PM<sub>2.5</sub> was 6.87 µg/m<sup>3</sup>, with the highest annual average occurring in 2007 at 8.0 µg/m<sup>3</sup>. Based on the NAAQS three-year average of 15 µg/m<sup>3</sup>, the annual average measured at the Flagstaff Middle School site was far below the acceptable threshold. The three year 24 hour average for the same years was 19.0 µg/m<sup>3</sup>. Given the new standard that was initiated in 2006 of 35µg/m<sup>3</sup>, this figure also falls well below acceptable levels. Similar to PM<sub>10</sub> three-year annual average, the highest 24-hour value occurred in 2007 at 47.5 µg/m<sup>3</sup>.

<b>Table xx. PM<sub>2.5</sub> Data (in µg/m<sup>3</sup>) 2005-2007</b>							
NAAQS annual average < or = 15 µg/m <sup>3</sup> over a three year time-period;							
Before 2006: NAAQS 24-hour average < or = 65 µg/m <sup>3</sup> over a three year time-period							
Beginning in 2006: NAAQS 24-hour average < or = 35µg/m <sup>3</sup> over a three year time-period							
	Annual Average	Three Year Annual Average	24 Hour Average		Three Year 24 Hour Average	Valid Data Recovery	
			Max Value	2nd High		No. of Obs.	% *
2005 PM <sub>2.5</sub> Data (in µg/m <sup>3</sup> ) **	6.01	6.87	18.9	12.7	19.0	55	90
2006 PM <sub>2.5</sub> Data (in µg/m <sup>3</sup> ) **	6.61		28.2	13.7		59	97
2007 PM <sub>2.5</sub> Data (in µg/m <sup>3</sup> ) **	8.0		47.5	30.2		58	95

\* % of observations that are valid.

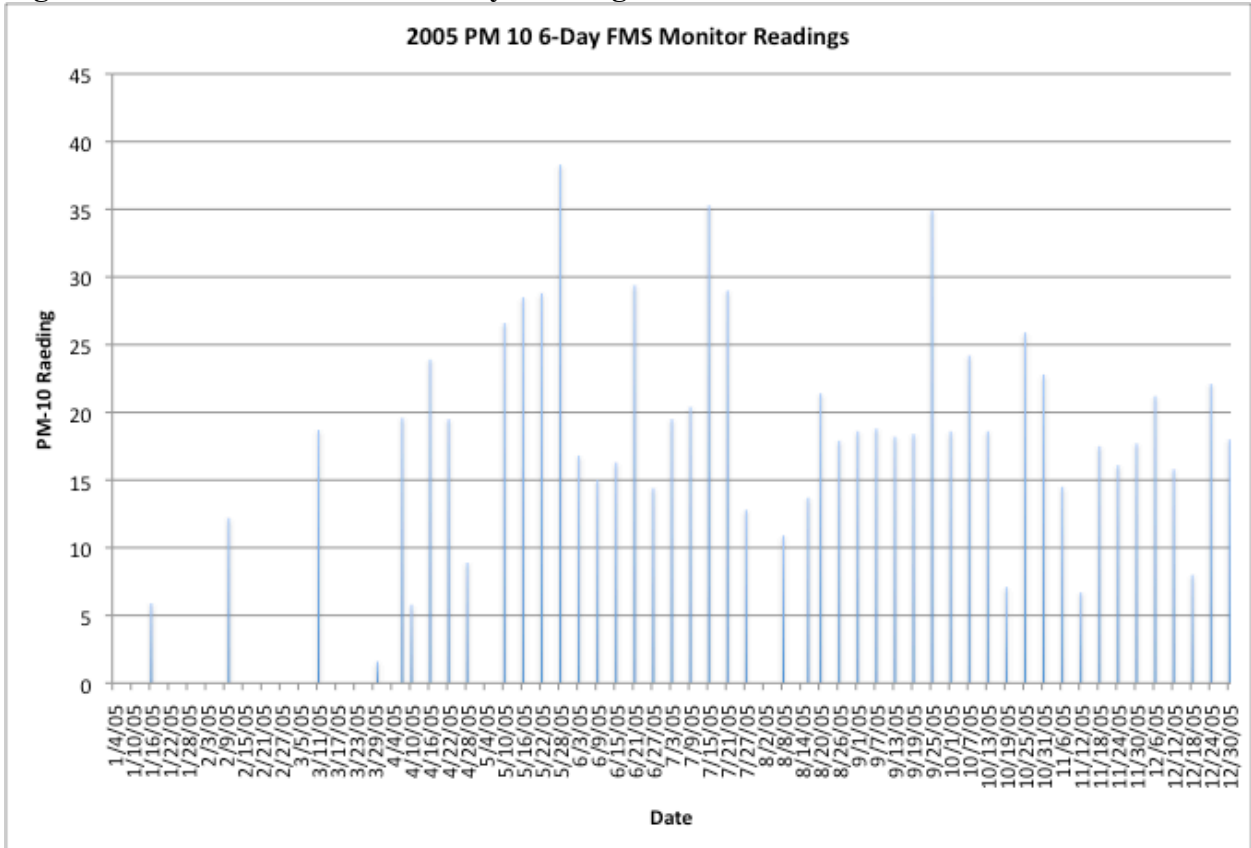
\*\* Samples collected every sixth day - 61 sample days in 2005.

(Adapted from ADEQ 2006, 2007, 2008)

## ADEQ Six Day Readings

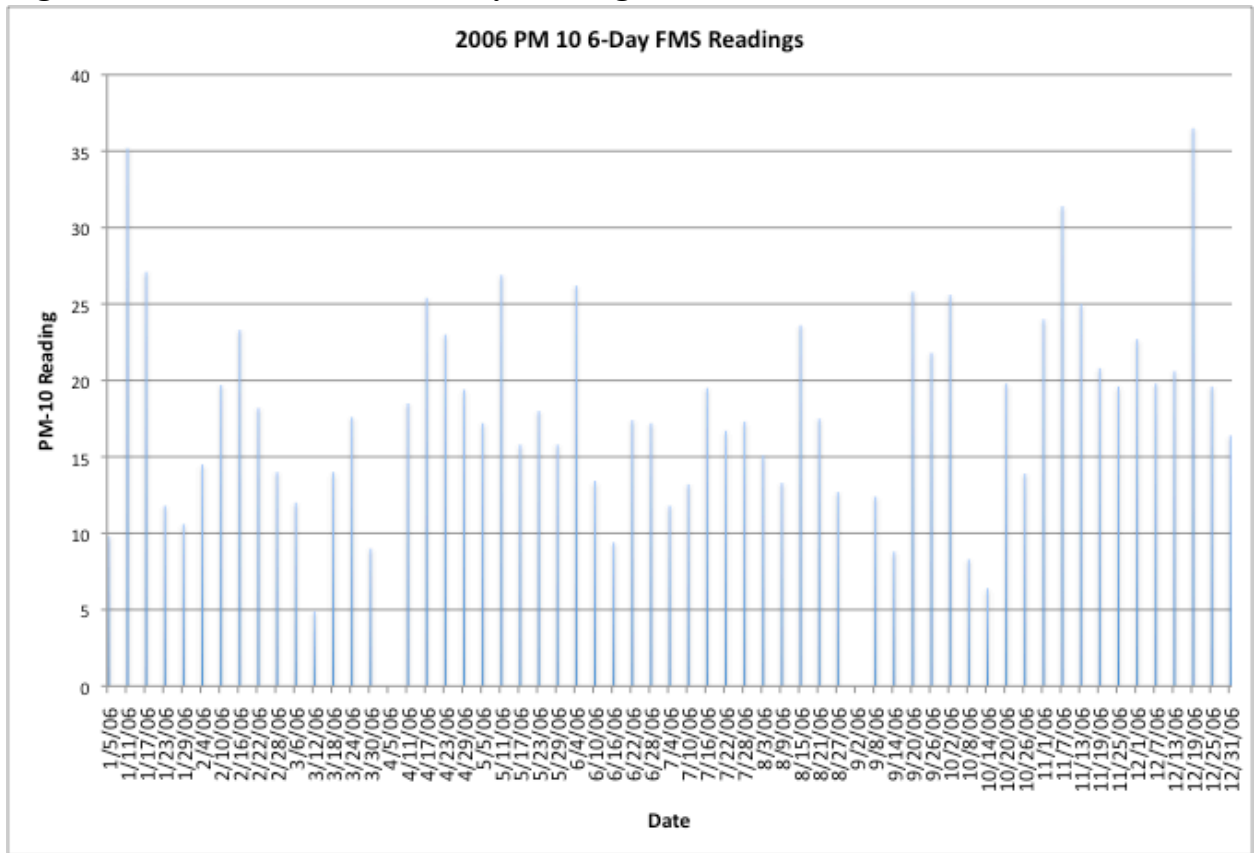
Although annual, three year and 24 hour averages are included in ADEQ’s Annual Reports, a more detailed account of the six day readings for years 2005-2007 were obtained directly from the Unit Manager Data Management - Quality Assurance Unit at the EPA (S Wardwell, EPA, personal communication) (see Appendix [xx](#)). These include monitor readings from the Flagstaff Middle School (FMS) site for both PM<sub>10</sub> and PM<sub>2.5</sub> levels, reported as daily values, sampled by ADEQ for 24 hours, from midnight to midnight, every six days (see Figures [xx-xx](#)). For days with a “null” or unrecorded reading, these indicate an error in the reading or one that was not collected (see Appendix [xx](#)). With this level of detail, these data more accurately reflect variation in PM levels and are more useful in comparing PM readings to prescribed fire and wildfire dates.

Figure xx. ADEQ 2005 PM<sub>10</sub> Six-Day Readings



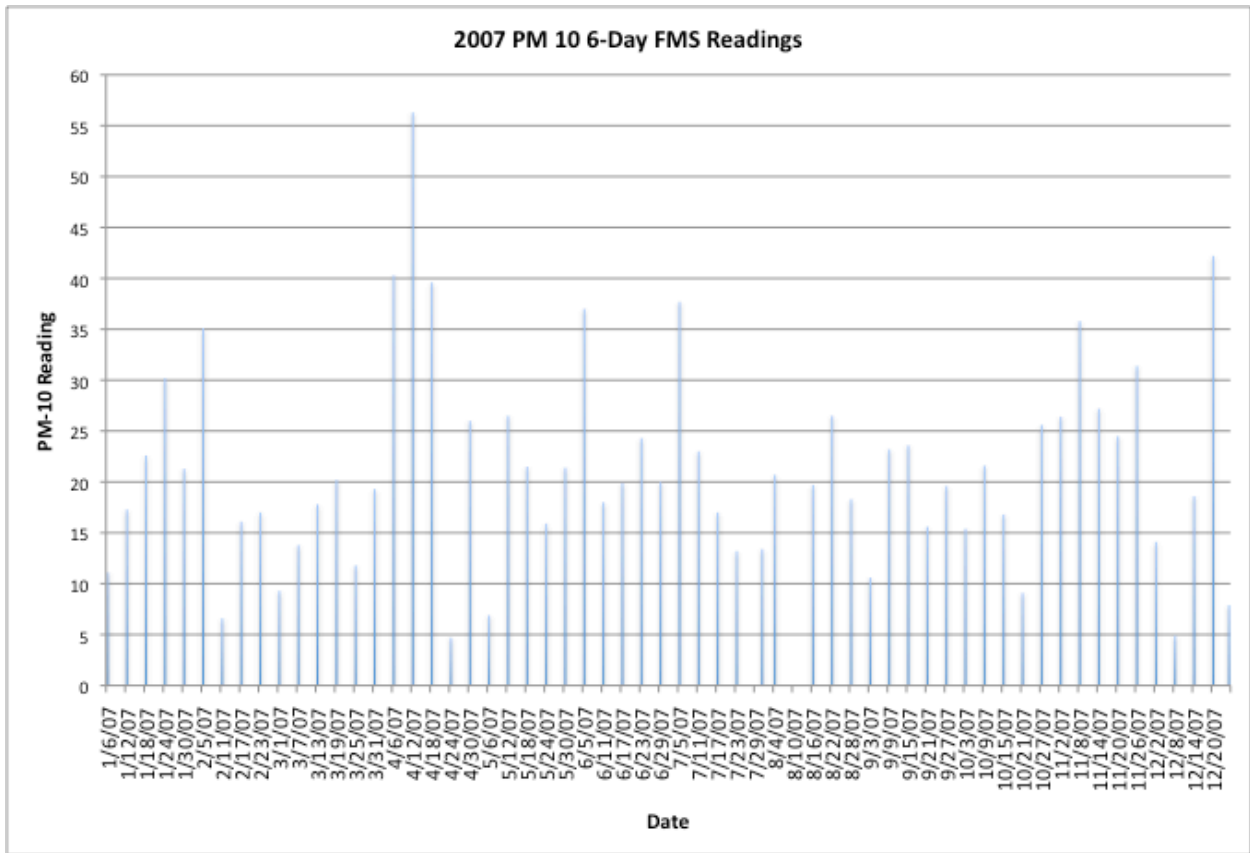
Source: ADEQ

Figure xx. ADEQ 2006 PM<sub>10</sub> Six-Day Readings



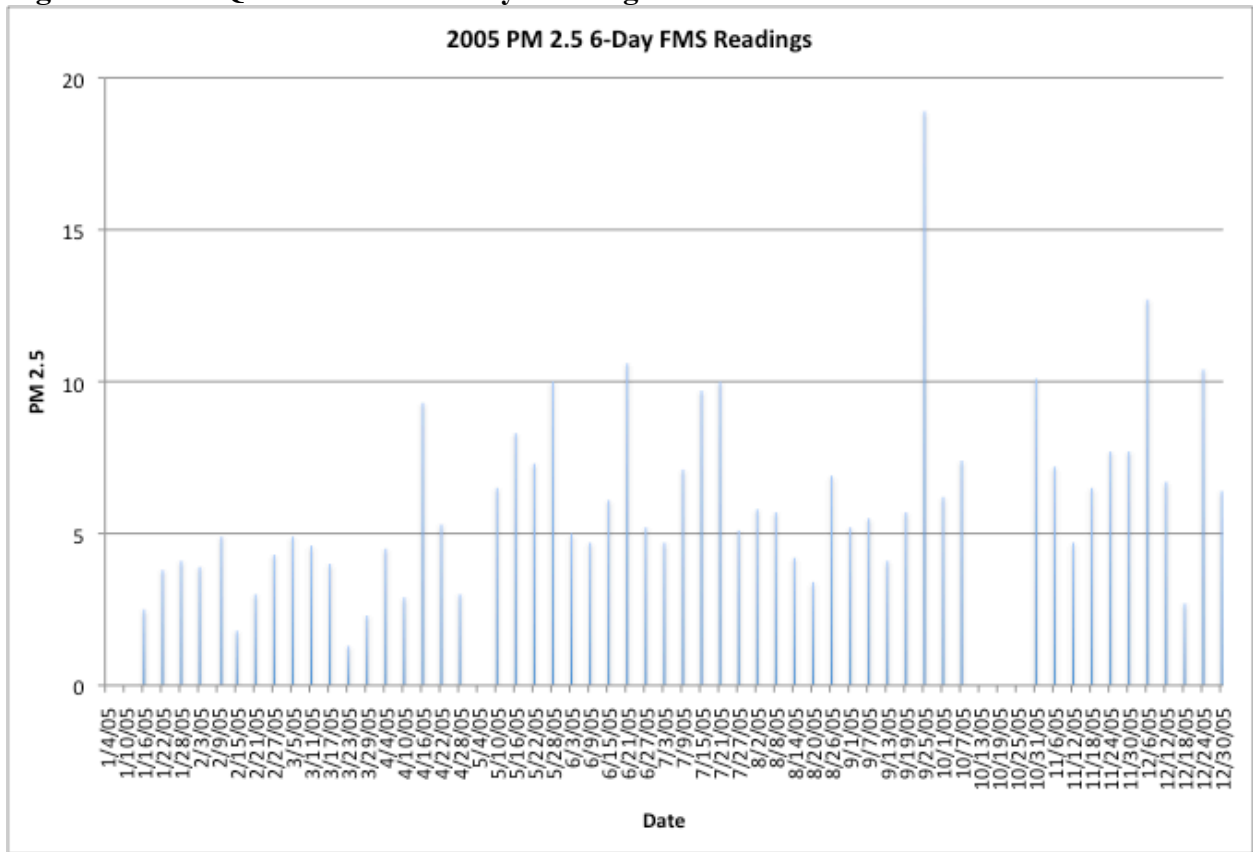
Source: ADEQ

Figure xx. ADEQ 2007 PM<sub>10</sub> Six-Day Readings



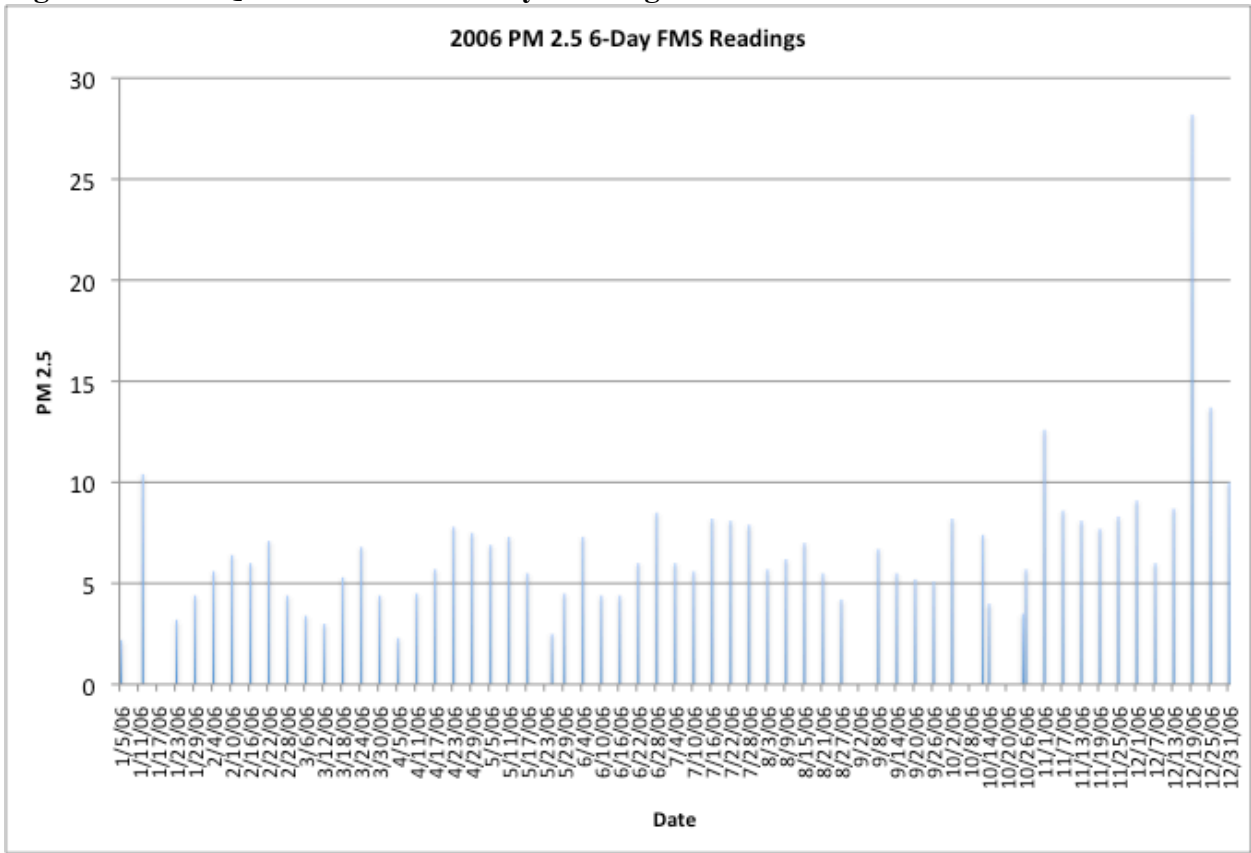
Source: ADEQ

Figure xx. ADEQ 2005 PM<sub>2.5</sub> Six-Day Readings



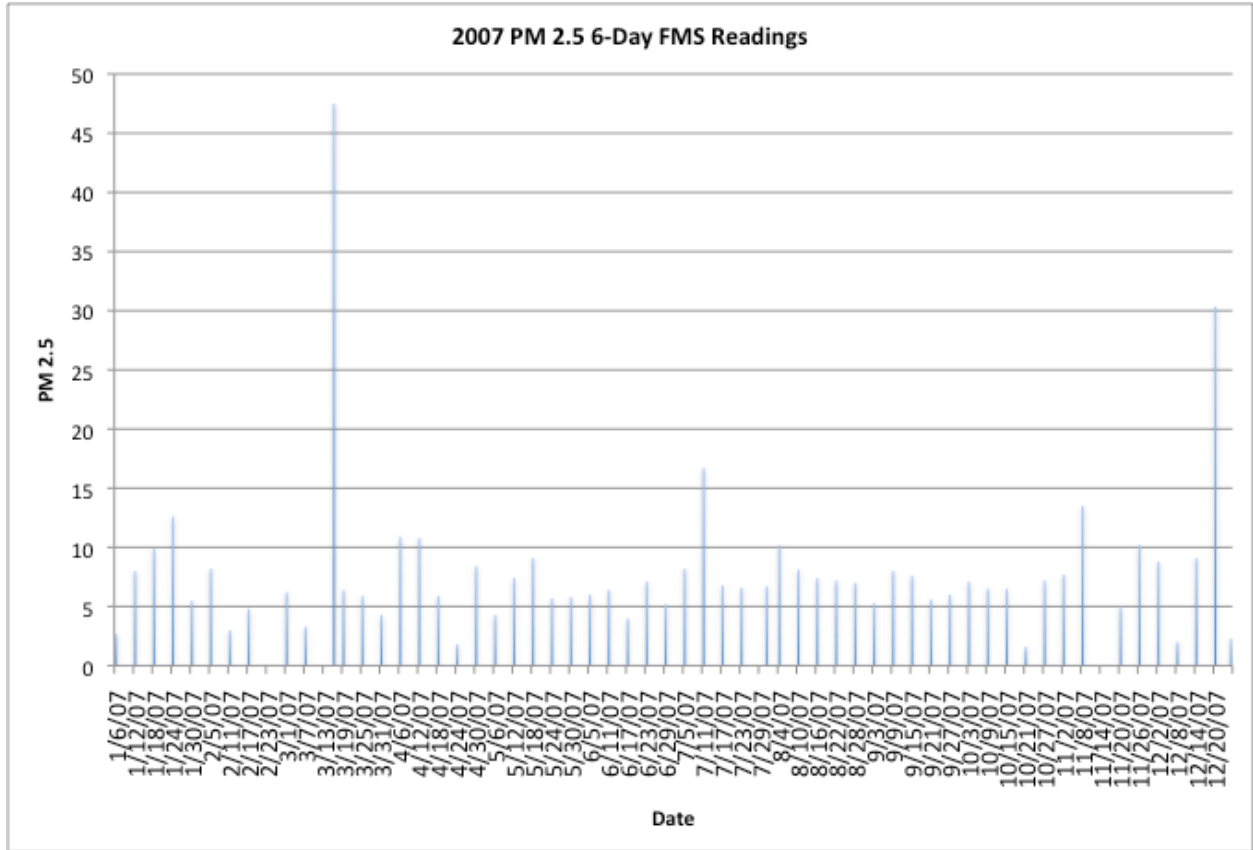
Source: ADEQ

Figure xx. ADEQ 2006 PM 2.5 Six-Day Readings



Source: ADEQ

Figure xx. ADEQ 2007 PM 2.5 Six-Day Readings



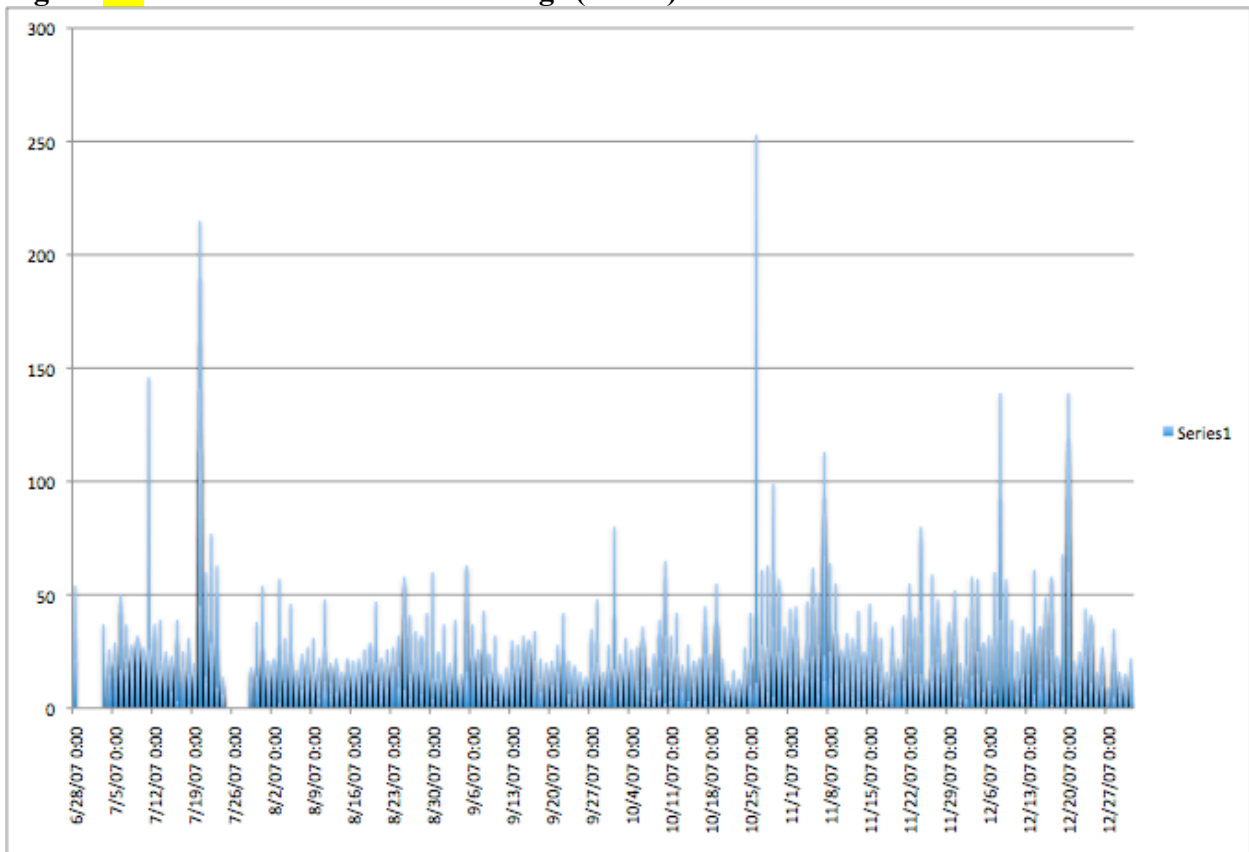
Source: ADEQ

## ADEQ Portable Particulate Monitors

### E-BAM Network of PM<sub>10</sub> Special Purpose Monitors

The ADEQ operates a network of Portable Particulate Monitors throughout Arizona, referred to as “E-BAM” (Beta Ray Attenuation Monitors) (ADEQ 2008). An E-BAM monitor was installed at the FMS site beginning June 28, 2007 (ibid). This monitor is continuous and records daily hourly average concentrations of PM<sub>10</sub> (ibid). Sampling takes place every second and PM<sub>10</sub> concentrations are recorded every minute (ibid). Figure xx depicts the FMS’s EBAM monitor readings from June 28, 2007 to December 31, 2007.

Figure xx. FMS EBAM monitor readings (PM<sub>10</sub>) from June 28th to December 31st 2007



Source: ADEQ 2009

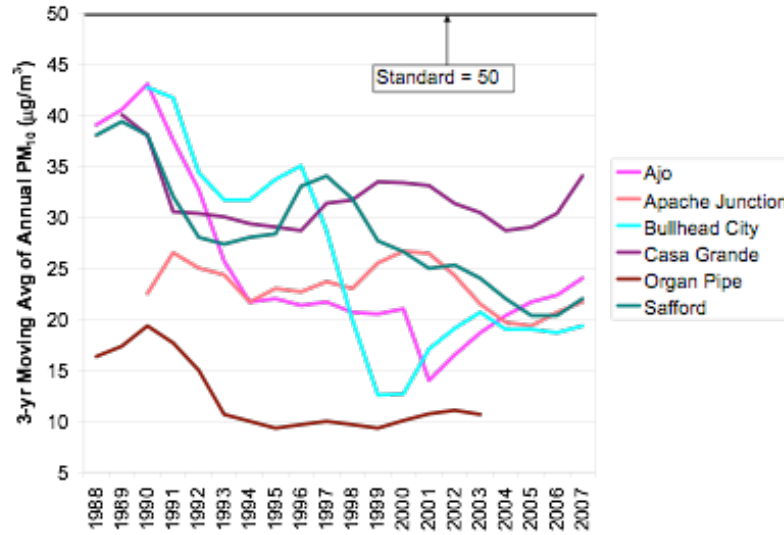
Near real time data from this monitor is available on ADEQ’s website (<http://www.phoenixvis.net/PPMmain.aspx>) to provide the public data recorded by the Portable Particulate Monitor (PPM) in areas where they are stationed (ADEQ 2009). However, readings from this monitor are not considered for attainment (NAAQS compliance) as they are highly biased; they are not subject to quality assurance review for accuracy as well as describe Air Quality Index (AQI) readings as an hourly reading (ibid). These AQI readings are strictly based on daily values; therefore, the scale at which the PPM’s data is reported as AQI is not consistent. Regardless, citizens, land managers, as well as ADEQ personnel can

initially use these data by to quickly assess considerable air quality changes. For example, the PM reading may determine accelerated level of PM<sub>10</sub> due to a wildfire or prescribed fire, informing smoke management decisions. In turn, this can alert both citizens, land managers, as well as ADEQ personnel to quickly assess the filter monitor 6-day readings, considered highly reliable and accurate, for compliance and any possible actions needed to notify the public and/or attempt to assess the source of the accelerated readings.

## **Trends**

Since the mid 1980s, the three-year moving average of annual PM<sub>10</sub> concentrations in Flagstaff have noticeably declined by more than 50 percent (approximately 34 µg/m<sup>3</sup> in 1987 to approximately 14 µg/m<sup>3</sup> in 1998) (see Figure xx) (ADEQ 2008). Part of these decreases can be attributed to cleaner-burning wood stoves and fireplaces (ibid). Since the lowest reading in 1998, modest increases have been observed to approximately 18 µg/m<sup>3</sup> in 2007 however; levels are nowhere nearly as high as they were in 1987.

**Figure xx.** Three year moving averages of annual average of PM<sub>10</sub> in Flagstaff and other sites with lower concentrations of PM<sub>10</sub> at higher elevations (ADEQ 2008).



**Figure 20 –** Three-year moving averages of annual average PM<sub>10</sub> concentrations at sites with lower concentrations at lower elevations



**Figure 21 –** Three-year moving averages of annual average PM<sub>10</sub> concentrations at sites with lower concentrations at higher elevations

PM<sub>2.5</sub> concentrations have not been monitored as long as PM<sub>10</sub>. PM<sub>2.5</sub> monitoring devices were not available until the early 1990s. Flagstaff's PM<sub>2.5</sub> concentrations (PM<sub>fine</sub>) in µg/m<sup>3</sup> ranged from 4.7 µg/m<sup>3</sup> in 1998 to a peak of 11.2 µg/m<sup>3</sup> in 1996 (see Figure xx). Flagstaff has had fairly constant concentrations from 2001 to 2006 (ranging from 5.6 µg/m<sup>3</sup> - 7.1 µg/m<sup>3</sup>), however a noticeable increase in concentration (8.0 µg/m<sup>3</sup>) was reported in 2007 (ibid).

Figure xx. The table and graph below depicts annual averages of PM<sub>2.5</sub> in Flagstaff from 1991 to 2007 (ADEQ 2008).

**Table 25a: Annual PM<sub>fine</sub> and PM<sub>2.5</sub> Concentrations Throughout Arizona (in µg/m<sup>3</sup>)**  
**Bold values in yellow exceed the annual standard of 15 µg/m<sup>3</sup>.**

Year	Yuma	Flagstaff	Payson	Nogales	Douglas
1991	7.6	N/A	<b>17.9</b>	12.3	8.5
1992	5.7	N/A	<b>17.2</b>	12.6	7.9
1993	6.1	5.4	13.0	9.7	7.9
1994	8.3	4.9	<b>15.8</b>	10.4	8.1
1995	7.2	5.8	<b>15.7</b>	14.3	7.7
1996	8.7	11.2	14.4	13.3	8.3
1997	6.0	5.0	12.2	11.3	6.0
1998	8.3	4.7	10.9	12.5	6.8
1999	7.9	8.4	9.8	12.5	7.9
2000	8.7	6.9	10.0	12.8	7.1
2001	10.0	7.1	8.8	10.7	7.2
2002	N/A	7.1	10.0	12.1	7.4
2003	N/A	5.6	8.9	11.3	6.4
2004	N/A	6.8	9.5	10.8	7.1
2005	N/A	6.0	8.3	13.1	7.3
2006	N/A	6.6	9.0	<b>15.6</b>	6.8
2007	N/A	8.0	9.4	12.3	7.7

N/A - Data are not available.

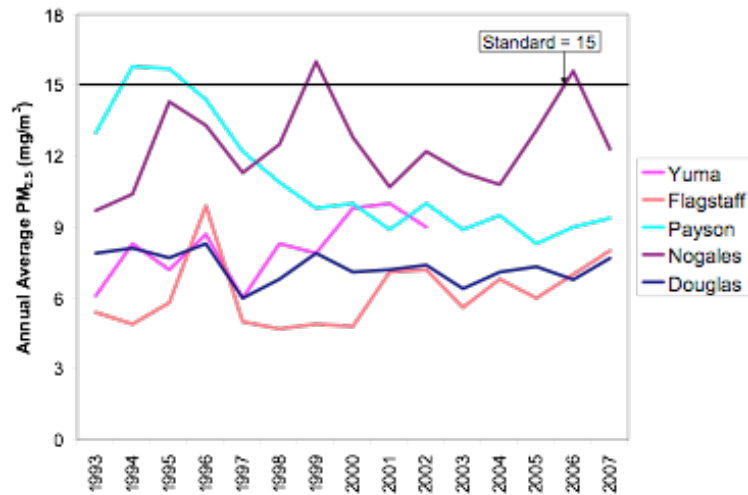


Figure 22 – Statewide annual averages of PM<sub>2.5</sub>

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## **Conclusion**

As past research is taken into account, these studies reveal ambiguities on the health impacts of smoke due to numerous inherent complexities in conducting research on the subject. Not only are there limits in obtaining smoke composition through air quality monitors, but also many argue these methods do not accurately reflect smoke exposure to a given population. These difficulties result from the number of monitors available to a study as well as their location (if they are located upwind of the fire, readings will not accurately reflect smoke concentrations). In addition, readings are based on 24-hour averages that may not reflect peaks that may occur for a few hours during a fire event.

Studies are also limited when taking into account only hospital/emergency room reports. By utilizing only these accounts, those that visit other health care establishments, such as primary care providers or walk-in health clinics, are eliminated from the study population which limits accurately establishing health effects from biomass burning on a given population. In addition, based on smoke behavior for a given fire, sectors of the study population may be more directly affected by the smoke than others.

Fowler (2003) further illustrates the limitations to the studies contained in his literature review finding that most research on smoke effects investigates single constituents of smoke and these studies tests the effects of these pollutants on human health from sources other than forest fires such as automobiles and industrial pollutants. Fowler (2003) further attests deficiencies of the research literature reviewed reveals the majority of studies consider short-term health outcomes, and only a few studies consider long-term health effects of exposure to biomass smoke. He further reflects on his review of recent literature and emphatically states, despite these limitations, research on the subject reveals an elevated interest of biomass smoke effects due to a combined interest from the public, within the scientific community, and among policy makers and land managers. Further, both Fowler (2003) and Sandberg and Dost (1990) suggest adding an ethnographic component to the studies, that includes direct perceptions of individuals that encounter extreme fire events. Sandberg and Dost (1990) stress that although there is a low probability of public health risks, an urgency for further research remains, “We urge the forest management community to consider health risks from exposure to prescribed fire smoke as our highest priority air quality issue.”

Ultimately, most agree that by using prescribed fire as a management tool, these actions reduce the possibility of intense wildfires that produce exorbitant amounts of smoke and by doing so, the cumulative and dramatic human health costs associated with them are drastically reduced (cited in Fowler 2003: Hardy et al. 2001; Viers 2005). Additionally Hardy (2001) explains prescribed fire management is designed to limit human health risk and land managers follow strict guidelines published by the USFS (and others) that provide instructions with the best methods to use in planning and deciding when to employ prescribed burns that will most dissipate associated health effects/costs (cited in Fowler 2003). There is also evidence that burn techniques have direct impact on reducing emissions. Sandberg and Dost (1990) found that scheduling prescribed/slash burns when it is wet, verses during the drier months, can reduce emissions by more than 50 percent.

In the end, Viers (2005) notes, as prescribed fires are conducted across the landscape and become more common, smoke management concerns will dissipate over time, due to lessened volumes of smoke generated from continued decreases of available forest fuel and generally less intense fires.

## **Recommendations for Phase II**

### **Health Effects Data**

Based on the studies reviewed, limiting health data to hospitals and emergency rooms will underestimate disease rates that have been reported to alternative health care facilities (Naehr et al. 2007). As outlined by the GFFP's Board of Directors' initial study design, including health data from not only the hospital and emergency room but also, from primary health care providers and urgent care/walk-in clinics, will assist in obtaining data that will more accurately reflect disease rates of the study population.

The list of primary health care providers submitted by NCHCC staff should be verified as exhaustive, containing all primary health care providers in Flagstaff. Once the list is formulated, providers can be approached with a written explanation of the study and an example data set to determine their willingness to participate as well as their ability to provide electronic archival data of the determined billing codes for years 2005 through 2007.

Results of literature reviewed revealed the most common ICD-9-CM codes used in emergency rooms and hospitals across studies. Using this list and, as recommended by the CDC (2003), determine which of the codes identified in the literature review reflect the most frequently used codes in the Flagstaff area. Once the list has been verified, submit the list of ICD-9-CM codes to NCHCC to rerun 2005-2007 data. The resulting data set can be used as a model for medical establishments to provide a data set with identical variables. With clear data set parameters defined in the front end, health care providers will unequivocally understand the data that is required for the study, which will ultimately encourage the likelihood of their participation. Lastly, as these data are provided, instruct the health care provider to limit the frequency of the disease indicator to one diagnostic code per patient per day, or if this proves difficult, analyze each code separately (Roberts and Corkhill 1998; CDC 2008).

Defining clear reference periods that parallel the temporal variation of fire occurrences as well as including at least two reference periods will increase the validity of the study (Lipsett et al. 1994; CDC 2008; Delfino et al. 2008). As suggested by Moore et al. (2006), analyzing historical data could illustrate seasonal variations of other sources of PM. Similarly to eliminate respiratory spikes more commonly observed in the winter months, conduct a separate analysis of the summer months and compare this to a analysis that spans the entire year (ibid). Generic demographic data of the study set (gender, age, etc.) as well as health data by county (AZDHS 2010) can be compared to that of the study areas' population to assess whether this data set represents the study population. Lastly, by including patient's zip codes in the data set, those that live outside of the study area can be eliminated (Tham et al. 2009).

Final analysis that includes ratios to compare the prescribed/wildfire fire occurrences with the reference periods, length of lag periods, as well as the specific statistical tests should be finalized after consulting a statistician.

## **Institutional Review Board Application**

Submit an Institutional Review Board application prior to beginning Phase II to ensure the protection of the human subjects in research.

## **Fire Occurrence Data**

Excluding the ASF division of the State Land Department, all prescribed fire and wildfire data sets have been provided and are available for the analysis of the study.

## **ADEQ Air Quality Monitors/Quantitative Models**

The SLAM Air Quality Monitor at the Flagstaff Middle School site is the only monitor in Flagstaff. As revealed in the literature review, the location of the air monitor is critical to assessing PM concentrations. During a fire event, if the monitor is located downwind of the fire, monitor readings will more likely reflect accurate PM concentrations. Conversely, if the monitor is upwind from the fire, the readings will most likely be an inaccurate reflection of the amounts of PM emitted from the fire (Chen et al. 2006; Naeher et al. 2007).

Moreover, many studies refute using 24-hour averages due to peaks in smoke penetration/PM levels during fire events. PM levels of smoke may peak above standards for a few hours before it disperses, but may not show as a violation in the 24-hour reading (Roberts and Corkill 1998; Sandberg et al. 2002; ADHS 2008; CDPH 2009). Researchers argue that violations that exceed standards for a short duration could result in the possibility of smoke affecting health or minimally causing physical irritation; however, NAAQS standards are not violated and therefore will not correlate with these effects (Sandberg et al. 2002).

Although the SLAM Air Quality Monitor has limitations, these measurements are the only empirical data available to measure PM. Using the six-day readings provided in this report will more accurately reflect PM variations as they are compared to prescribed/wildfire dates. In addition, in assessing the regulated and measured pollutants in wood smoke, fine particulates (PM<sub>2.5</sub>) have proved to be the most accurate and reliable metric in measuring exposure as well as the most elevated and sensitive to existing air quality standards measurements (Naeher et al. 2007; Delfino et al. 2008).

In addition to air quality monitoring data, quantitative models could be used to assess the amount of PM emitted during fire events. Similar to the PM readings, fire models have limitations; however, if quantitative modeling is determined a viable option, the most current models should be studied to assess the applicability to ponderosa pine forests of the southwest, and whether these models are easily accessed and contain a reasonable user interface. Data reflected in the model could supplement results stemming from the SLAM monitor. A possible scenario is to combine air quality monitoring and computer modeling by

using the air monitor results for fires downwind from the monitor (determined by location-township and range) and, when fires are upwind, determine effects from the computer model.

Adding to the inherent difficulty of relying on the efficacy of air quality monitors as well as computer models, other atmospheric conditions that may exist at the same time of year, that include dust, automobile and fireplace emissions, allergens, etc., will confound an explicit determination that health impacts are caused from prescribed fire smoke alone. Thus, using the information and methodology provided in this report, as Phase II is developed, these extraneous variables should be considered in the analysis.

Additionally, for Phase II, including a review of current Emission Reduction Techniques (ERT) and Smoke Management Techniques (SMT) of land management agencies in the Flagstaff area should be considered.

## References (not complete)

Add contact page ADEQ, NCHCC, FFD, USFS etc. (Appendix)  
Personal communication

Christopher Field. The Velocity of Climate Change,” a free lecture open to the public at 7 p.m. Oct. 21 at the NAU’s High Country Conference Center. is based upon his work with the United Nations’ [Intergovernmental Panel on Climate Change](#) and as director of the Carnegie Institution’s [Global Ecology Department](#) at Stanford University.

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Craig D. Allen; Savage, M.; Falk, D. A.; Suckling, K. F.; Thomas, W. Swetnam; T. W.; Schulte, T.; Stacey P. B.; Penelope, M.; Hoffman, M.; and Klingel, J. T. 2002. *Ecological Restoration of Southwestern Ponderosa Pine Ecosystems: A Broad Perspective*. Ecological Applications, 12(5), pp. 1418–1433 2002 by the Ecological Society of America.

Arizona Department of Environmental Quality, ADEQ Permits: Permit Classifications. Last revision March 3, 2009. Retrieved May 15, 2009 from <http://www.azdeq.gov/environ/air/permits/class.html>.

ADEQ Air Quality Division, Air Assessment Section. *State of Arizona Air Monitoring Network Plan for the Year 2009*. Final Report July 1, 2009. Retrieved October 13, 2009 from <http://www.azdeq.gov/environ/air/monitoring/download/ADEQ%202009%20Monitoring%20Network%20Plan%209-25-09.pdf>

ADEQ Air Quality Division, Air Assessment Section. *State of Arizona Air Monitoring Network Plan for the Year 2008*. Final Report June 30, 2008. Retrieved May 23, 2009 from <http://www.azdeq.gov/environ/air/monitoring/>

[download/2008plan.pdf](#)

Arizona Department of Environmental Quality. Air Quality Division. Portable Particulate Monitors. Last Revision October 13, 2009. Retrieved October 13, 2009 from <http://www.phoenixvis.net/PPMmain.aspx>.

ADEQ, Janet, Stephen A. Ownes. 2006 *Air Quality Annual Report* (ARS 49-424.10). Retrieved May 22, 2008 from <http://www.azdeq.gov/function/forms/download/2006/aqd.pdf>

ADEQ, Janet, Stephen A. Ownes. ADEQ, Janet, Stephen A. Ownes. 2007 *Air Quality Annual Report* (ARS 49-424.10). Retrieved May 23, 2008 from <http://www.azdeq.gov/environ/air/monitoring/download/2007air.pdf>

ADEQ, Janet, Stephen A. Owens. 2008 *Air Quality Annual Report* (ARS 49-424.10). Retrieved May 23, 2008 from <http://www.azdeq.gov/function/forms/download/2008air.pdf> <http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf>

ADHS Bureau of Public Health Statistics, Health Status and Vital Statistics Section. 2010. Retrieved April 28, 2010 from <http://www.azdhs.gov/plan/index.htm>  
Statistics for asthma: <http://www.azdhs.gov/plan/hip/for/asthma/index.htm>

Arizona Department of State. Environmental Quality. Title 18. R18-2-1507. Department of Environmental Quality Air Pollution Control Chapter 2 Article\_15. 2005-2009. Retrieved May 15, 2009 from [http://www.azsos.gov/public\\_services/Title\\_18/18-02.htm](http://www.azsos.gov/public_services/Title_18/18-02.htm)

Center for Disease Control; 2003. Syndrome definitions for diseases associated with critical bioterrorism-associated agents, October 23, 2003. Atlanta, GA:US Department of Health and Human Services, Retrieved May 24, 2010 from <http://www.bt.cdc.gov/surveillance/syndromedef/word/syndromedefinitions.doc>

Dahms, Cathy, and Brian Geils. 1997. An assessment of forest ecosystem health in the Southwest. General Technical Report RM-GTR-295. Fort Collins, Colorado: USDA Forest Service, Rocky Mountain Research Station.

EPA AirData: Access to Air Pollution Data by State. Last updated November 6, 2008. Retrieved May 21, 2009 from <http://www.epa.gov/air/data/repstst.html?st~AZ~Arizona>

Hays, M. D., Geron, C. D., Linna, K. J., Smith, N. D., and Schauer, J. J. 2002. *Speciation of gas-phase and fine particle emissions from burning of foliar fuels*. *Environ. Sci. Technol.* 36(11):2281–2295. 5(4):391–408.

Hereford, Richard, 2007, Climate variation at Flagstaff, Arizona; 1950 to 2007: U.S. Geological Survey Open-File Report 2007-1410, 17 p. Version 1.0, January 9, 2008.

Retrieved January 9, 2009 from <http://pubs.usgs.gov/of/2007/1410/>. Initial release online at <http://pubs.usgs.gov/of/2007/1410/>

Institutional Review Board for the Protection of Human Subjects in Research. Northern Arizona University. "What projects require IRB review?" Arizona Board of Regents. 2010. Retrieved October 12, 2010 from:  
<http://www.research.nau.edu/compliance/irb/Quick%20Reference/What%20Projects%20Require%20IRB%20Review.pdf>

Kleeman, M. J., Schauer, J. J., and Cass, G. R. 1999. Size and composition distribution of fine particulate matter emitted from wood burning, meat charbroiling, and cigarettes. *Environ. Sci. Technol.* 33(20):3516–3523.

Lipsett, Michael, Barbara Materna, Susan Lyon Stone, Shannon Therriault, Robert Blaisdell and Jeff Cook. *Wildfire Smoke - A Guide for Public Health Officials*. Revised July 2008. Retrieved November 15, 2008 from  
<http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf>.

Pyne, Stephen J. 1982. *Fire in America*. Princeton, NJ: Princeton University Press.

State of Arizona Air Monitoring Network Plan (SAAMNP) For the Year 2008. Arizona Department of Environmental Quality Air Quality Division. Air Assessment Section. Final Report. June 30, 2008. Retrieved May 23, 2009 from  
<http://www.azdeq.gov/environ/air/monitoring/download/2008plan.pdf>

Southwest Coordination Center (SWCC) Predictive Services. Intelligence. Updated May 21, 2009. Retrieved May 21, 2009 from  
[http://gacc.nifc.gov/swcc/predictive/intelligence/ytd\\_historical\\_data/historical/suppression/maps/fires\\_az\\_2007.jpg](http://gacc.nifc.gov/swcc/predictive/intelligence/ytd_historical_data/historical/suppression/maps/fires_az_2007.jpg) (maps of all wildfires in AZ 2007) If used

Southwest Coordination Center (SWCC) Predictive Services. Intelligence. Updated May 21, 2009. Retrieved May 21, 2009 from  
[http://gacc.nifc.gov/swcc/predictive/intelligence/ytd\\_historical\\_data/historical/suppression/large\\_fires/2006/2006\\_eoy\\_large\\_map\\_az.jpg](http://gacc.nifc.gov/swcc/predictive/intelligence/ytd_historical_data/historical/suppression/large_fires/2006/2006_eoy_large_map_az.jpg)

Southwest Coordination Center (SWCC) Predictive Services. Intelligence. Updated May 21, 2009. Retrieved May 21, 2009 from  
[http://gacc.nifc.gov/swcc/predictive/intelligence/ytd\\_historical\\_data/historical/suppression/large\\_fires/2005/2005\\_eoy\\_large\\_map\\_az.jpg](http://gacc.nifc.gov/swcc/predictive/intelligence/ytd_historical_data/historical/suppression/large_fires/2005/2005_eoy_large_map_az.jpg)

Sapkota, A., Symons, J. M., Kleissl, J., Wang, L., Parlange, M. B., Ondoy, J., Breyse, P. N., Diette, G. B., Eggleston, P. A., and Buckley, T. J. 2005. Impact of the 2002 Canadian forest fires on PM air quality in Baltimore City. *Environ. Sci. Technol.* 39(1):24–32.

U.S. Department of the Interior; U.S. Department of Agriculture. 1995. Federal wildland fire management policy and program review. Final report. Boise, ID: Bureau of Land Management. 45 p.

U.S. Environmental Protection Agency. 1992a. Prescribed burning background document and technical information document for prescribed burning best available control measures. EPA-450/2- 92-003. Office of Air Quality Planning and Standards. September.

U.S. Environmental Protection Agency. Technology Transfer Network. Air Quality System. Obtaining AQS Data. Last updated July 30, 2009. Retrieved October 15, 2009 from <http://www.epa.gov/ttn/airs/airsaqs/detaildata/>

Wiedinmyer, Christine and, Matthew D. Hurteau 2010. *Prescribed Fire As a Means of Reducing Forest Carbon Emissions in the Western United States. Environ. Sci. Technol.* 44 (6), pp 1926–1932.