# Smoke Management: An Emerging Profession[1]

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**Abstract.**—Smoke management is increasing as an activity conducted by federal land management agencies throughout the United States. Efforts to meet air quality regulations affecting smoke management will succeed as fire managers plan for smoke management as an integral aspect of burn prescriptions. Operational tools are now available for use, though continuing improvement of smoke management hinges on research and development to advance the capabilities of the science. An example of smoke management planning using available tools is presented.

The Southwest has beautiful desert landscapes, forested mountains, and a rapidly growing population. People expect clean air and unrestricted vistas. They complain when their visibility is reduced. Visibility reduction is caused by pollution transported into the region from the large urban complex of Los Angeles as well as from the growing metropolitan area within the region. People are generally not aware that smoke from forest burning has historically been a part of the landscape and their tolerance for smoke is rather low. Diurnal wind patterns exist in the Southwest because of the strong radiative heating in daytime and cooling at night. These winds transport residual smoke from forest burning in the mountains into valley bottoms where towns and cities are often located.

Land management in the region must use fire to accomplish a variety of goals ranging from habitat improvement to natural fuel reduction. For example, the various land management agencies have prescribed fire programs covering 100,000 acres of ponderosa pine fuels and 5,000 acres of chaparral fuels per year. Both pile-burning and broadcast-burning are used to reduce these fuels.

In order to ensure that smoke from prescribed burning does not become a problem, the state air quality divisions in Arizona and New Mexico use a permit system. In Arizona a permit application is made yearly and permission is granted to burn on a day-to-day basis dependent on dispersion and weather conditions. This system generally allows adequate flexibility for both prescribed burning programs and smoke management. But, smoke management must be a significant component of the program.

## A Smokey Day in Sedona

The need for smoke management can be demonstrated by a recent incident in Sedona, Arizona. In September 1988, about 400 acres of hand-piled ponderosa pine logging slash (fuel loading was approximately 18 tons/acre) was burned. The burn was on the Mogollon Rim about 2000 feet above and 12 miles north by northwest of Sedona. Knowing that down-canyon nighttime airflows transport smoke into town, the burn boss followed a smoke management plan limiting ignition to only 200 acres each day. Still, Sedona suffered an impairment of visibility on three successive mornings after the burn was ignited. Elevated levels of particulates disturbed those suffering from asthma and allergies.

Factors that contributed to the smoke problem in Sedona are the nighttime drainage wind flow, development of an inversion that limited dispersion, and a large total loading of smoke from a number of sources including fireplaces and wood stoves. At the same time, transport of pollution from long distances into the area may have made a significant contribution.

Before the prescribed burning season, a press release to area media and letters to key people announced the potential for smoke to limit visibility in populated areas. Nevertheless, there was significant public concern about the amount of smoke.

Several points can be made about this incident. Even though the burn boss used a responsible fire prescription and smoke management plan, the outcome was unexpected. Covering piles and burning them when good dispersion is assured, coordinating the allowable number of actively burning acres near sensitive

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areas, expanding the burning season, reducing the total acres ignited per day, mopping up, and broadcast-burning rather than pile-burning are examples of options that can be considered. Because of the complexity of both topographic and meteorological conditions surrounding such burns, site burn prescriptions may need to utilize more expensive and complex techniques, including meteorological measurement and modeling technology. In this paper we will apply state-of-the-science planning tools to this example to look at some of these alternatives.

## The Professional Smoke Manager

The art of "smoke management" is developing into a profession. To many, the term focuses on regulatory concerns for air quality standards as enforced by federal, state, or local authorities. Regulatory agencies have no responsibility to consider smoke from the ecological perspective understood by a land manager. They generally have no knowledge of the role fire has played historically and needs to continue to play in the management of natural resources. They do not recognize that fuel accumulation must be managed to prevent excessive buildups that lead to catastrophic fires, a predictable consequence of a management policy of no fuel treatment.

Rather, regulatory agencies view burning from an engineering and economic perspective. Burning activities to reduce fuel loads in slash or to prepare planting sites are often viewed as commercial activities in the same sense as a coal-fired powerplant is a commercial activity. Regulators consider smoke from prescribed fires particulate pollution. Their job is to maintain air quality within federal and state standards.

While land managers understand that fire has an historical presence and that a little smoke from prescribed fires is better than a lot of smoke from wildfires, regulators worry about each day's pollution loading in the airshed. Their job is to manage these loadings. And in the conduct of this management, the largest sources are considered for control first. If calculations and data suggest that forest burning is the primary source of small inhalable particulates (e.g., $PM_{10}$ particles less than 10 m in diameter), then forest burning becomes a regulator's target. Thus, it is not surprising that land managers and regulators approach smoke management with somewhat different perspectives.

Regulations affecting prescribed burning fall into three categories. Ambient air quality standards are set at a specific concentration selected to ensure that public health will be protected. The Federal Clean Air Act of 1977 mandates these standards. For example, the ambient standard for $PM_{10}$ is 150 $g/m^3$, a 24-hour average concentration that is not to be exceeded more than once a year. This standard should not be violated on areas "off the site" of a fire.[5]

The second type of standard results from the Clean Air Act Prevention of Significant Deterioration (PSD) regulations. These can be described as esthetic standards. They are formally applied to stationary sources (e.g., coal-fired power plants) and allow for incremental degradation of air quality by specific pollutant increments above a baseline set by the first applicable industrial development.

These regulations also require the protection of air quality related values, including visibility, in Class I areas.[6] While it is clear that Congress wished Class I areas to be protected from visibility degradation caused by industrial sources, there is no mention of prescribed fire related visibility reduction in the PSD section.

The Clean Air Act mandates a state-centered regulatory process. Each state has the responsibility to establish whatever regulatory structure it wishes, subject only to the constraint that its ambient standards are at least as stringent as the federal standards. Furthermore, State Implementation Plans (SIP) codify a process to achieve air quality goals. A state may, therefore, choose to regulate smoke from prescribed fire.

The third type of regulation used to control fire emissions is requiring state and local permits for open burning. Although there are often provisions allowing exemption for agricultural burning, slash burning or range treatment by burning usually are not considered agriculture. Open burning requirements often include provisions that the burner not impugn the health, safety, well-being, or enjoyment of the public. Specific safety provisions to insure that highways or towns are not filled with smoke are common and are enforced.

If smoke management is to develop as a profession, it must develop techniques to allow prescribed burning to be conducted without violating air quality regulations. The professional smoke manager must understand such things as air quality regulation developments and implementation, the fundamentals of fire behavior, the use of fire as a land management tool, the effects of fire emissions on health and welfare, the influences of meteorology on dispersion/transport of fire emissions, the basics of simulation of the dispersion of smoke, and the practice of public information. The mix of skills needed by smoke managers is not, to our knowledge, currently supplied in any university program. It is one which

*[5] For air quality impacts, "off the site" normally refers to the boundary of private property within which the public does not have general access. For prescribed burns, the Wyoming Air Quality Division has arbitrarily defined "off the site" as 1 km from the advancing fire front.*

*[6] National parks, wilderness areas, and similar lands above certain size categories that existed in August 1977 when the Act was passed are set aside for special air quality protection and minimal air quality degradation.*

we feel must be recognized and encouraged for courses of study at universities.

### Current Practices in Smoke Management

In some states elaborate smoke management plans and procedures have been developed. Oregon fires are scheduled based on centralized daily determinations of dispersion meteorology. Dispersion forecasts are made for seasons when fire is allowable (during those times when transport of smoke into Class I areas will not likely lessen the enjoyment of visitors). In Wyoming fires are permitted by the state air quality authority only after they have been modeled to demonstrate that air standards are not likely to be violated. In most of the Southwestern states, open burning regulations of some kind already exist.

Operational tools applicable to smoke management now include monitoring devices, databases, and models. Monitoring devices include particulate monitors for $PM_{10}$, meteorology measuring devices such as remote automatic weather stations (RAWS), and various "sounders" that collect information on wind, temperature, and humidity distribution at various atmospheric levels.

Examples of databases which can be used are the BLM Initial Attack Management System (IAMS) data and the developing USFS Weather Information Management System (WIMS). Models available for use are the USFS Pacific Northwest Station Emission Production Model (EPM) for calculation of fire emissions and the USFS Rocky Mountain Station/BLM Topographic Air Pollution Analysis System (TAPAS, an interactive system of terrain-based dispersion and wind simulation models) (Fox et al. 1987).

All of these tools require knowledgeable personnel to use them. None of them is so simple that it can be used without thought. As an example, consider the collection and use of weather data.

### Collection and Use of Weather Data

Often the most significant smoke management question is, What is the best way to use weather data? Classically, fire weather data has been collected as input to the National Fire Danger Rating System (NFDRS) (Deeming et al. 1972). These observations have been archived and are available through the National Fire Weather Data Library (NFWDL, Furman and Brink 1975). NFDRS provides indication of fire potential and NFWDL provides an historical fire weather data base. But these systems include only a daily observation at the location of the weather station, often a valley bottom near a Ranger Station. They sometimes do not represent the actual weather condition at the burn site. Currently efforts are underway in the USFS to develop a Forest Service Weather Information System (WIMS, Bass et al. 1988). WIMS will be a comprehensive microprocessor-based, graphics-oriented system that will integrate data and information from the following:

- RAWS—the existing network of fixed Remote Automated Weather Stations.
- P-RAWS—portable RAWS deployed at an activity site for a limited time period.
- NFDRS—the on-line weather and interpreted fire parameter national output.
- BLM-IAMS—the BLM Initial Attack Management System of lightning and weather information.
- NOAA/NESDIS/NWS—weather from remotely sensed data on surface temperatures, cloud cover, temperatures, and soil moisture; coupled with numerical models to forecast weather and biomass moisture.
- Other electronically available data and model products.

By the mid-1990s WIMS will be integrated with Geographic Information Systems (GIS) to provide data interactively. In the interim these data are not available to the on-the-ground smoke manager. RAWS and AFFIRMS (NFDRS) data are available, but of limited utility to the smoke manager because of sparse collection density and the unavailability of upper air data at the fire weather site.[7]

Complete upper air data would provide the smoke manager with an indication of the wind and atmospheric stability in the vicinity of a burn. Coupling this data with a detailed flow model for complex terrain, such as TAPAS, the manager could then simulate where smoke would go and calculate how much visibility would be reduced and particulate concentrations increased when it arrives. Unfortunately, upper air patterns do not remain fixed or stationary. As the sun goes down,

*[7]The best measurement device to determine upper air wind patterns is the balloon. Two separate types of balloons with associated instrumentation are useful. One is a tethered balloon, about 3 m long, which lifts an instrument package. The instrumentation sends back data on the temperature (wet and dry bulb), wind speed, wind direction, and pressure. These data allow the plotting of wind with height up to approximately 500 m. The instrumentation is reasonably portable so that data can be obtained at a number of locations. A second balloon technology uses free-flying balloons about 1 m in diameter that have small attached instrumentation packages. These balloons fly free and rise through the atmosphere. By tracking them with theodolites, a picture of the wind speed and direction can be obtained. The instrument package sends data on temperature, pressure, and humidity back to the ground. This package provides a complete description of the atmosphere along the balloon path.*

the surface cools and drainage flows develop, and the atmospheric boundary layer collapses and traps smoke underneath it. These phenomena are predictable in general, but not in specific or particular. Thus, even with the relatively sophisticated tools described, smoke will often end up where it is not desired—particularly while a fire remains in a smoldering stage at night.

While the future of smoke management lies in the application of measurement technologies along with modeling, we would like to illustrate the use of a simple smoke dispersion screening model, the Simple Approach Smoke Estimation Model (SASEM) (Riebau et al. 1988), in a real smoke management planning situation.[8] Although the more complex models in TAPAS can provide a better prediction, particularly when coupled with good on-site data of smoke trajectories, the basic features of smoke management can be illustrated with SASEM.

We suggest that smoke managers should use SASEM now as a tool for planning before burning. Figure 1 illustrates three levels of modeling progressing from simple screening to complex research models. As a screening model, SASEM will provide estimations of visibility and particulate concentrations inexpensively with a margin of safety.

[8]*Screening models are simplified models that are deliberately designed to over-predict impacts. By over-prediction of impacts, screening models provide a quick estimation of the worst case possible; if such a model were to provide exact estimations of monitoring data, it would be a failure as a screening model. By predicting the worst possible impacts, SASEM provides managers with a wide margin of safety. Thus, if SASEM predicts that smoke management objectives will be met (i.e., visibility impairment will be minimal and air quality standards will not be violated), there is no need for more complex analyses and the project can go forward. If SASEM predicts undesirable impacts, two courses of action are possible. One is to reduce emissions; the second is to utilize a more accurate, less conservative model.*

## Arizona Broadcast-Burn Example

Let's consider an example where, in the fall, a forest manager plans to broadcast-burn an area of approximately 3,500 acres to reduce/remove decaying cull logs, natural downfall, and remaining debris from commercial timber harvest. The fuels involved average 19 tons per acre: fire specialists on the forest choose the following fire weather parameters:

| Fuel type | Fuel moisture (%) | Fuel weight (tons/acre) |
|---|---|---|
| Live fuels | n/a | n/a |
| 1-hr fuels | 5 - 15 | 00.2 |
| 10-hr fuels | 6 - 15 | 00.8 |
| 100-hr fuels | 7 - 18 | 04.3 |
| 1000-hr fuels | n/a | 13.8 |
| **Air temperature (°F)** | **Relative humidity (%)** | **Wind speed (mph)** |
| 50-80 (day) | 15 - 50 | 1 - 6 |
| 30-60 (night) | 15 - 50 | 1 - 6 |

So that scorch height would not exceed 13 to 15 feet to avoid damaging the standing trees (pole height), it would be unmanageable to burn all 3,500 acres in one session, so all burns are limited to 200 acres to complete the flaming phase of combustion within 10 hours.[9] Under the conditions of the prescription, fire line intensities are calculated to be from 41 to 123 BTU/ft/sec.[10]

SASEM was designed to model smoke emission and dispersion from just such fire prescription information. For each fire SASEM requires the following input data:

- number of acres to be burned
- fuel loading in tons per acre
- fuel type (in this instance woody was used)
- fire line intensity

[9]*It was estimated that smoldering might go on for up to 3 days.*

[10]*Roy Hall, Fuels Management Technician, Coconino National Forest, personal communication.*

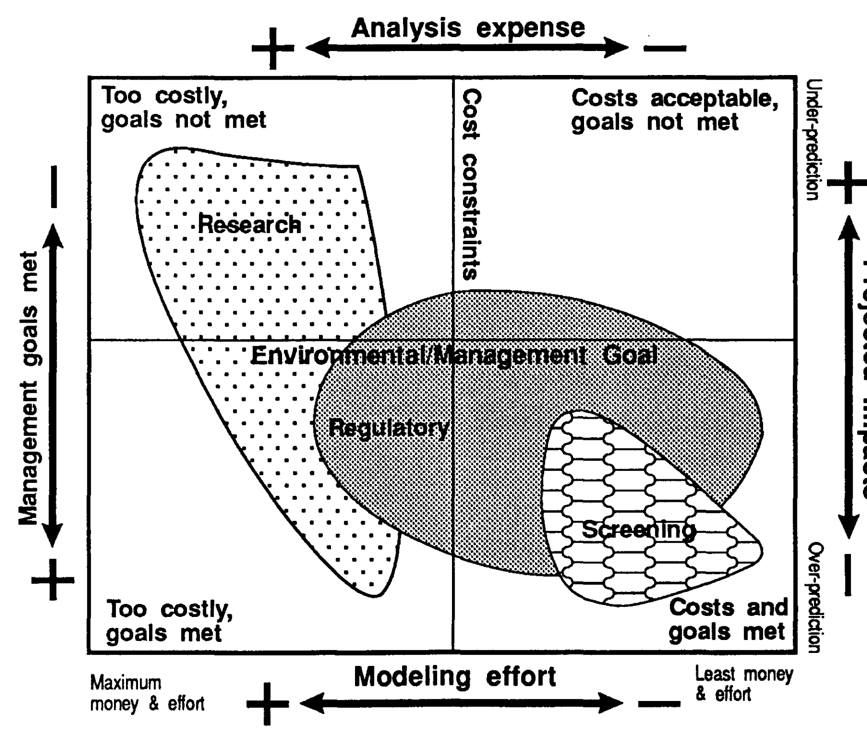


Figure 1.—Models: research, regulatory, screening (smoke management purposes).

- burn duration in hours

- wind speed in MPH.

As an indication of the maximum loading potential, SASEM, on the entire 3,500 acres to be burned, predicts 381 tons of particulate to be produced (11.4 g/Kg of fuel). In this case, SASEM predicts that the maximum offsite concentration would be 9 times the ambient standard (approximately 1,400 g/m$^3$) under poor dispersion conditions (e.g., PG Class E or F) and 1 mph windspeed. The burning of 200 acres at a time results in offsite concentrations that would not violate ambient standards except in limited areas under the poorest dispersion conditions and low wind speeds.

One of the useful features of SASEM is its ability to estimate visibility (atmospheric optical clarity) at remote receptors. For this example, we have located a receptor 11 miles from the fire. SASEM reports visibility in miles of visual range. In simple terms, visual range indicates how far one might be able to see under the worst case if smoke were transported directly to the receptor (e.g., plume centerline). To demonstrate the usefulness of this tool for fire planning, SASEM was run with several burn durations to show the different impacts possible.[11] Figure 2 presents these estimates for different meteorological conditions. Varying burn duration and thus emission rate from the fire changes the visibility impact predictions.

*[11]It should be noted that varying the burn duration could vary to scorch height and thus not meet the fire objectives. Visibility objectives must then be considered in the matrix of other burn objectives.*

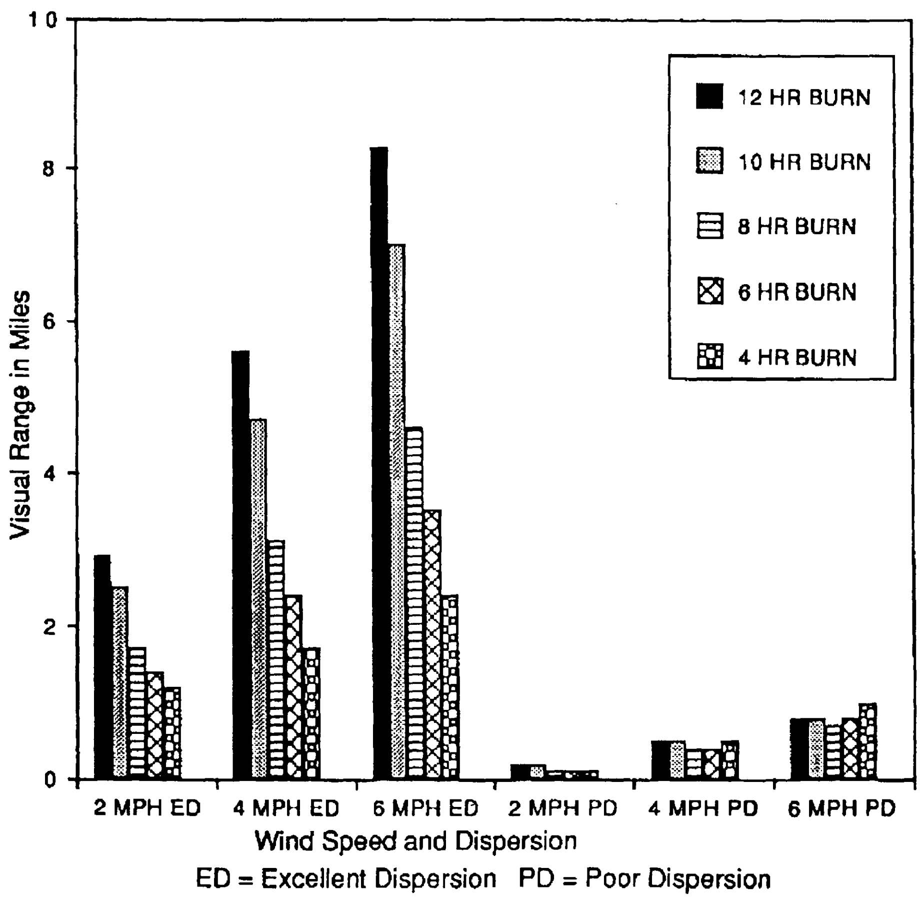


**Figure 2.—Visual range with burn duration, Sedona, Arizona (200 acres, woody fuels).**

As can be seen from the example SASEM analysis as depicted in figures 3 and 4, modifying the fire's management will result in little lessening of impacts to visibility. Figures 2 and 3 clearly show that the fuels involved will produce enough smoke to cause visibility impairment if the smoke gets there. Modifying either the acreage or the duration of the burn would not significantly lessen impacts. If this planned burn is in a similar location to our example 11 miles NNW of Sedona, Arizona, it is clear that under low wind speed and limited dispersion conditions typical of that routinely occurring in drainage flows, SASEM predicts visibility could be reduced to less than 1 mile and particulate loads could exceed 4-6 times the ambient standard. As SASEM is designed as a screening model, these high pollution predictions are worst case. They should never actually occur because if they did, the model would not be overpredicting. However, the SASEM prediction does "red flag" this burn for managers. Although the actual predictions are larger than what is likely to actually happen, the manager needs to consider that there may be other burning in the region and weigh the risk of polluting Sedona against the likely resultant consequences. SASEM illustrates that the "risk adverse" choice for the fire manager is to extinguish the fire before drainage flows transport the smoke to Sedona. If this alternative is unacceptable, the manager will need to develop more information by investing in meteorological measurements and using the more expensive, complex, and accurate models contained in TAPAS.

## The Southwestern Smoke Management Perspective

The Southwest has several air quality issues before it. The Sedona incident underscores the need for a professional commitment to smoke management by the groups that conduct prescribed burning. Compliance with the provisions of state programs, and professional smoke management will increase the costs of prescribed burns. The possibility of periodically having to fully suppress a prescribed burn to alleviate smoke impacts to a sensitive area is real. Acceptance of appropriate costs by agencies is necessary to integrate effective smoke management as a component of prescribed burning.

**Conclusions**

The profession of smoke management will be defined by smoke management professionals themselves. Paradoxically, this profession is still so undefined that few, if any, true smoke managers exist. The archetype smoke manager must be trained in fire behavior and ecology, fire management, dispersion meteorology, fire emissions calculation, air quality regulations and regulatory processes, dispersion and ecological modeling, and public relations. This particular and challenging mix of skills has not yet been formally addressed by the nation's universities, although various federal land management agencies have attempted to address training in these areas through internal programs.

Smoke management means that the effects of smoke are incorporated into burn plans before burning, monitored during the burn, and assessed for impacts after the fact. We suggest that SASEM can be a valuable screening tool and should be used in the development of burn plans with potential to impact sensitive areas.

Smoke managers also need a mix of tools to practice their profession. The most important tool needed by smoke managers is adequate meteorological data for both surface and upper air conditions. Without these data smoke management can not be practiced in any real sense. Another tool is accurate emission factors for open fires. The necessity of having accurate and dependable factors is paramount. Also, an important tool is a set of dispersion models in addition to SASEM which can accurately predict smoke transport and pollutant concentrations at sites remote from the fire itself.

To develop these skills and tools there is a need for continued research. Emission factors must be developed that are specific for fuel types common to the Southwest. Research has been done to develop emission factors for fuels in both the northwestern and southeastern United States. These factors cannot be applied to southwestern fuel types without field testing to see if they are applicable. In addition, the collection and dissemination of local meteorological data to smoke managers is needed. Basic research on the influence of local meteorology on smoke transport and dispersion will aid the smoke manager as well as the fire planner. Screening models like SASEM err on the side of overprediction. They bias uncertainties to cause overprediction. However, overpredicting the consequences of prescribed burning can be costly. Added attention to the burn, reduced allowable fuel loadings, and limited burning acreages all add to the cost and limit opportunities to achieve management goals.

Modeling of smoke dispersion in complex terrain is an area that needs development. A basic question, such as how high the plume from a fire will rise, must be studied. Much work remains to provide truly reliable modeling tools that are palatable to regulators and more useful to smoke management planning. Research for all of these issues and others we have not highlighted in this paper, when complete must be transferred with their proper background

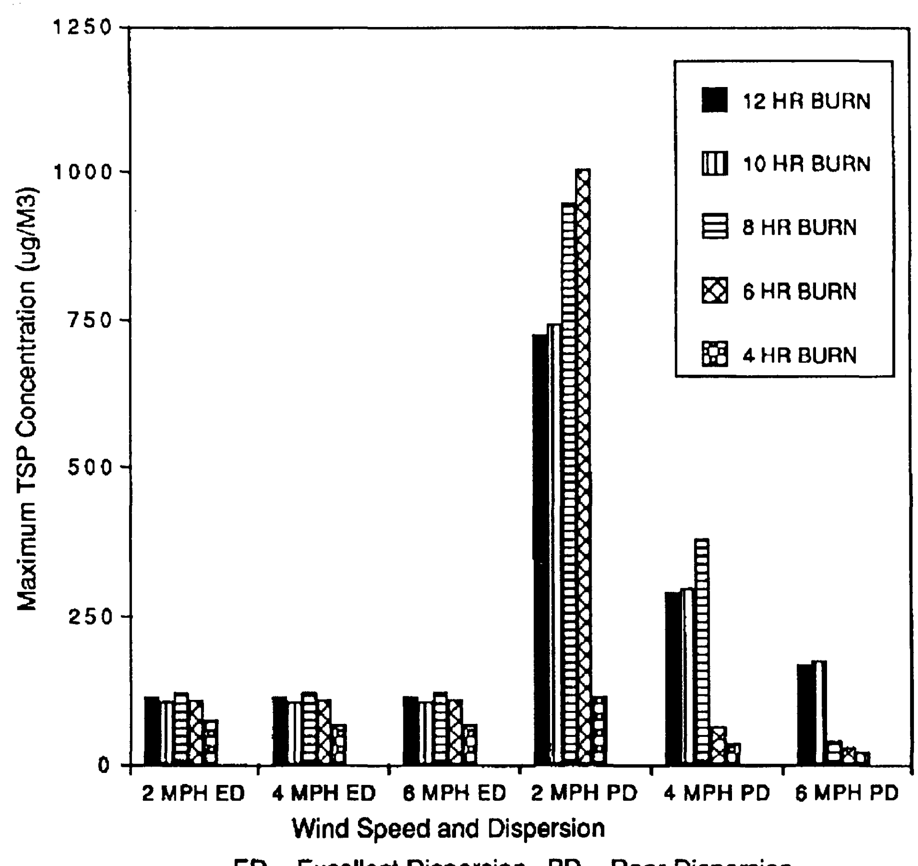


**Figure 3.—Max TSP conc with burn duration, Sedona, Arizona (200 acres, woody fuels).**

materials into a formal smoke management educational program most properly conducted at universities.

Where will we find professional smoke management in the final analysis? Professional smoke management must be part of every fire plan in a meaningful and useful way. If we don't meet the prescribed smoke management conditions, we don't burn. Professional smoke management must also be recognized in state regulatory programs. Professional smoke management must have a recognized body of professional-level tools backed by solid research. Finally, it must have practitioners who function as professionals.

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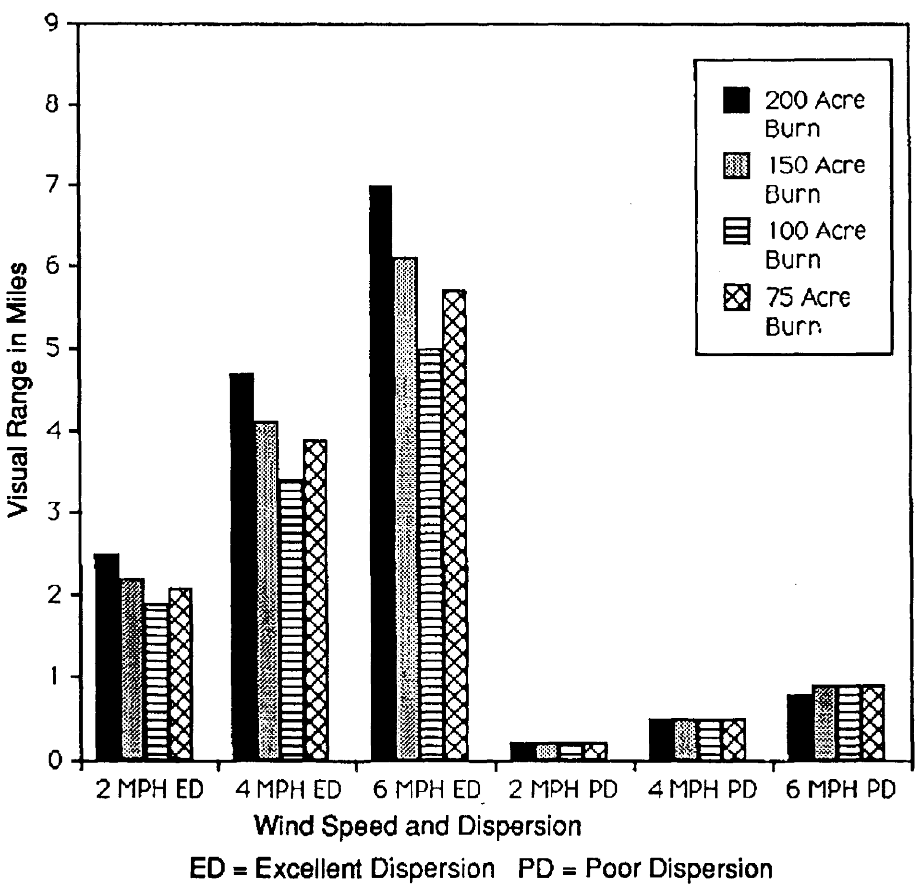


**Figure 4.—Visual ranges with burn acreage, Sedona, Arizona (broadcast - woody fuels).**