Chapter 1

INTRODUCTION

Introduction

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Why Do We Need A National Smoke Management Guide?

As an ecological process, wildland fire is essential in creating and maintaining functional ecosystems and achieving other land use objectives. As a decomposition process, wildland fire produces combustion byproducts that are harmful to human health and welfare. Both the land management benefits from using wildland fire and the public health and welfare effects from wildland fire smoke are well documented. The challenge in using wildland fire is balancing the public interest objectives of protecting human health and welfare and sustaining ecological integrity.

Minimizing the adverse effects of smoke on human health and welfare while maximizing the effectiveness of using wildland fire is an integrated and collaborative activity. Everyone interested in natural resource management is responsible and has a role. Land managers need to assure that using wildland fire is the most effective alternative of achieving the land management objectives. State, regional, tribal and national air resource managers must ensure that air quality rules and regulations equitably accommodate all legal emission sources.

The varied smoke management issues from across the nation involve many diverse cultures and interests, include a multitude of strategies and tactics, and cover a heterogeneous landscape. No national answer or cookbook approach will adequately address them. But people with a desire for responsible smoke management working in partnership with the latest science-based smoke management information can fashion effective regional smoke management plans and programs to address their individual and collective objectives. The intent of the Guide is to provide the latest science-based smoke management information from across the nation to facilitate these collaborative efforts.

Awareness of smoke production, transport, and effects on receptors from prescribed and wildland fires will enable us to refine existing smoke management strategies and to develop better smoke management plans and programs in the future. This Guide addresses the basic control strategies for minimizing the adverse effects of smoke on human health and welfare—thus maximizing the effectiveness of using wildland fire. These control strategies are:

- Avoidance – using meteorological conditions when scheduling burning in order to avoid incursions of wildland fire smoke into smoke sensitive areas.
- Dilution – controlling the rate of emissions or scheduling for dispersion to assure tolerable concentrations of smoke in designated areas.

- Emissions-reduction – using techniques to minimize the smoke output per unit area treated and decrease the contribution to regional haze as well as intrusions into designated areas.

Guide Goals and Considerations

The Smoke Management Guide steering committee and the NWCG Fire Use Working Team developed this Guide with the following goals:

- Provide fire use practitioners with a fundamental understanding of fire-emissions processes and impacts, regulatory objectives, and tools for the management of smoke from wildland fires.
- Provide local, state, tribal, and federal air quality managers with background information related to the wildland fire and emissions processes and air, land and wildland fire management.

The following considerations provide the context within which these goals can be met:

- This document is about smoke management, not about the decision to use wildland fire or its alternatives. Its purpose is not to advocate for or against the use of fire to meet land management objectives.
- While the Guide contains relevant background material and resources generally useful to development of smoke management programs, it is not a tutorial on how to develop a state smoke management program.
- Although the Guide is replete with information and examples for potential application at the local and regional level, the Guide generally focuses on national smoke management principles. For maximum benefit to local or regional applications, appropriate supplements should be developed for the scale or geographical location of the respective application.
- The Guide is more appropriate for knowledgeable air, land, and wildland fire managers, and is not intended for novice readers.

Overview and Organization of the Guide

The ***Smoke Management Guide for Prescribed and Wildland Fire–2001 Edition*** follows a textbook model so that it can be used as a supplemental reference in smoke management training sessions and courses such as the NWCG Smoke Management course, RX-410 (formerly RX-450). Following an **Introduction**, a background chapter presents a primer on wildland fire and a discussion of the imperatives for smoke management. In the **Wildland Fire Imperative,** the Guide addresses both the ecological and societal aspects of wildland fire (not agricultural, construction debris, or other biomass burning), and provides the details necessary for fire use practitioners and air quality managers to understand the fundamentals of fire in wildlands. **The Smoke Management Imperative** discusses the needs for smoke management as well as its benefits and costs.

The background sections are followed by chapters presenting details on **Wildland Fire Smoke Impacts—**public health, visibility, problem and nuisance smoke, and smoke exposure among fireline personnel—and on **Regulations for Smoke Management**. The chapter on **Smoke Source Characteristics** follows a sequence similar to the basic pathway that smoke production does—from the pre-fire fuel characteristics and the fire phenomenon as an emissions source, through the processes of combustion, biomass consumption and emissions production.

The chapter on **Fire Use Planning** addresses important considerations for developing a comprehensive fire use plan (a “burn plan”). The general planning process is reviewed, from developing a general land use plan, through a fire management plan and, ultimately, to a unit-specific burn plan.

The **Smoke Management Meteorology** chapter presents a primer on the use of weather observations and forecasts, and then provides information regarding the transport and dispersion of smoke from wildland fires.

Techniques to Reduce or Redistribute Emissions are presented in an exhaustive list and synthesis of emissions reduction and impact reduction practices and techniques. These practices and techniques were initially compiled as the outcomes of three regional workshops held specifically for the purpose of synthesizing current and potential smoke management tools. Presented here in a nationally applicable format, they are the fundamental tools available to fire planners and fire use practitioners for the management and mitigation of smoke from wildland fires.

The **Smoke Dispersion Prediction Systems** chapter reviews current prediction tools within the context of three “families” of model applications—screening, planning, or regulating.

Air Quality Monitoring for Smoke discusses various objectives for monitoring, and emphasizes the need to carefully match the monitoring objective with the appropriate equipment. In addition, the chapter presents information on some common monitoring equipment, methods, and their associated costs.

Emission Inventories help managers and regulators understand how to better include fire in an emissions inventory. This chapter discusses the use of the three basic elements needed to perform an emission inventory—area burned, fuel consumed, and appropriate emission factor(s).

No smoke management effort can succeed without continued assessment and feedback. The chapter on **Program Administration and Assessment** discusses the need to maintain a balance between the level of effort in a program and the level of prescribed or fire use activity as well as their associated local or regional effects.

Each section in this Guide is now supported by an extensive list of relevant references. Also, authorship for a specific section is given in the table of contents, where appropriate. In such cases, the section can be cited with its respective author(s) as an independent “chapter” in the Guide.

A glossary of frequently used fire and smoke management terms[1] is provided as an appendix to the Guide.

History of Smoke Management Guidance

The first guidance document specifically addressing the management of smoke from prescribed fires was the *Southern Smoke Management Guidebook*, produced in 1976 by the Southern Forest Fire Laboratory staff

[1] For a comprehensive presentation of fire terminology, the reader should refer to the NWCG *Glossary of Wildland Fire Terminology* (NWCG 1996—PMS #205, Boise, ID).

(1976). It was a comprehensive treatment of the various aspects fire behavior, emissions, transport and dispersion, and the management of smoke in the southern United States.

In 1985, NWCG's Prescribed Fire and Fire Effects Working Team developed the widely accepted *Prescribed Fire Smoke Management Guide* that forms the basis for this 2001 revised Guide (NWCG 1985). The 1985 edition focused on national smoke management principles and, as a result, was far less comprehensive than the Southern guidebook.

One of six state-of-knowledge reports prepared for the 1978 National Fire Effects Workshop is a review called *Effects of Fire on Air* (USDA Forest Service 1978). The six volumes, called the "Rainbow Series" on fire effects, were in response to the changes in policies, laws, regulations, and initiatives. Objectives specific to the volume on air were to: "…summarize the current state-of-knowledge of the effects of forest burning on the air resource, and to define research questions of high priority for the management of smoke from prescribed and wild fires" (USDA Forest Service 1978, p.5).[2]

Conflicts between prescribed fire and air quality began to be seriously addressed in the mid-1980s. Prior to this, only a few states had developed or implemented smoke management programs, and national-level policies addressing smoke from wildland burns were only beginning to be drafted. Much has changed since then, with numerous policies and initiatives raising the potential for conflicting resource management objectives—principally air quality and ecosystem integrity. The Clean Air Act amendments adopted in 1990 specifically addressed regional haze. Smoke Management Plans have been developed by many states as administrative rules enforceable under state law. These rules are often incorporated into State and Tribal Implementation Plans (SIPs and TIPs) for submission to the U.S. Environmental Protection Agency (EPA) and, once promulgated by EPA, are then enforceable under federal law as well. And now, the role of fire and the need for its accelerated use has become widely recognized with respect to maintenance and restoration of fire-adapted ecosystems. These issues all point to the imperative for better knowledge and more informed collaboration between managers of both the air and terrestrial resources.

The 2001 Edition of the Smoke Management Guide

Recognizing the increasing likelihood of impacting the public, the proliferation of federal, state, and local statutes, rules and ordinances pertaining to smoke, as well as major improvements to our knowledge of smoke and its management, the NWCG Fire Use Working Team (formerly named the Prescribed Fire and Fire Effects Working Team) sponsored revision of the Guide. Conceptually, the Fire Use Working Team identified the need for a revised guidebook that targeted not just prescribed fire practitioners, but state and local air quality and public health agency personnel as well. A consequence of this expansion of the target audience was the need to substantially augment the background information with respect to fire in wildlands.

A suite of potential smoke management practices and techniques are not only suggested in

[2] The Joint Fire Sciences Program is sponsoring extensive revisions to the Rainbow Series fire effects volumes, including a new volume on fire effects on air.

this Guide, but their relative effectiveness and regionally-specific applicability are also provided. This information was acquired through three regional workshops held in collaboration with the U.S. Environmental Protection Agency's Office of Air Quality Planning and Standards.

This revised Guide now emphasizes both emission and impact reduction methods that have been found to be practical, useful, and beneficial. This new emphasis on reducing emissions is in response to regional haze and fine particle ($PM_{2.5}$) control programs that will require emission reductions from a wide variety of pollution sources (including prescribed and wildland fire). This is especially important in view of the major increases in the use of fire projected by federal land managers. Readers will also find a greatly expanded discussion of air quality regulatory requirements, reflecting the growing complexities and demands on today's fire practitioners.

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Chapter 2

OVERVIEW

The Wildland Fire Imperative

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Perpetuating America's Natural Heritage: Balancing Wildland Management Needs and the Public Interest

Strategies for responsible and effective smoke management cannot be developed without careful consideration of the ecological and the societal impacts of fire management in the wildlands of modern America. The need to consider both perspectives is acknowledged by most land management agencies, as well as by the U.S. Environmental Protection Agency (EPA) —the primary Federal agency responsible for protecting air quality. An awareness of this challenge is reflected in NWCG's education message, *Managing Wildland Fire: Balancing America's Natural Heritage and the Public Interest* (NWCG 1998). The preamble to this document not only states that "fire is an important and inevitable part of America's wildlands," but also recognizes that "wildland fires can produce both benefits and damages—to the environment and to people's interests."

The EPA's Interim Air Quality Policy on Wildland and Prescribed Fires (U.S. EPA 1998) employs similar language to describe related public policy goals: (1) To allow fire to function, as nearly as possible, in its natural role in maintaining healthy wildland ecosystems; and, (2) To protect public health and welfare by mitigating the impacts of air pollutant emissions on air quality and visibility. The document comments on the responsibilities of wildland owners/managers and State/tribal air quality managers to coordinate fire activities, minimize air pollutant emissions, manage smoke from prescribed fires as well as wildland fires used for resource benefits, and establish emergency action programs to mitigate the unavoidable impacts on the public. In addition, EPA asserts that "this policy is not intended to limit opportunities by private wildland owners/managers to use fire so that burning can be increased on publicly owned wildlands."

In this and the following section (2.2–The Smoke Management Imperative), we outline both ecological and societal aspects of wildland and prescribed fire. We review the historical role and extent of fire and the effects of settlement and land use changes. The influence of fire exclusion policies on historical disturbance processes is considered in light of modern landscape conditions. This provides the basis for discussion of significant, recent changes in Federal wildland fire policy and new initiatives for accelerating use of prescribed and wildland fire to achieve resource management objectives. Finally, we present examples of the impacts of wildland smoke on air quality, human health, and safety.

Fire in Wildlands

Recurring fires are often an essential component of the natural environment—as natural as rain, snow, or wind. Evidence for the recurrence of past fires is found in charcoal layers of lakes and bogs, in fire-scars of trees, and in the morphological and life history adaptations of numerous native plants and animals. Many ecosystems in North America and throughout the world are fire-dependent (Heinselman 1978) and periodic burning is essential for healthy ecosystem functioning in these wildlands. Fire acts at the individual, population, and community levels and can influence:

- Plant succession.
- Fuel accumulation and decay.
- Recruitment pattern and age distribution of individuals.
- Species composition of vegetation.
- Disease and insect pathogens.
- Nutrient cycles and energy flows.
- Biotic productivity, diversity, and stability.
- Habitat structure for wildlife.

For millennia, lightning, volcanoes, and people have ignited fires in wildland ecosystems. The current emphasis on ecosystem management calls for the maintenance of interactions between such disturbance processes and ecosystem functions. Therefore, it is incumbent on both fire and natural resource managers to understand the range of historical frequency, severity, and aerial extent of past burns. This knowledge provides a frame of reference for applying appropriate management practices on a landscape scale, including the use and exclusion of fire.

Many studies have described the historical occurrence of fires throughout the world. For example, Swetnam (1993) used fire scars to describe a 2000-year period of fire history in giant sequoia groves in California. He found that frequent small fires occurred during a warm period from about A.D. 1000 to 1300, and less frequent but more widespread fires occurred during cooler periods from about A.D. 500-1000 and after 1300. Swain (1973) determined from lake sediment analyses in the Boundary Waters Canoe Area in Minnesota that tree species and fire had interacted in complex ways over a 10,000-year period. Other studies ranging from Maine (e.g. Copenheaver and others 2000) to Florida (e.g. Watts and others 1992) have employed pollen and charcoal deposits to demonstrate shifts in fire frequency correlated with the onset of European settlement.

There is an even larger body of science that details the numerous effects of wildland fires on components of ecosystems. Some of the most compelling examples of fire dependency come from studies on plant reproduction and establishment. For instance, there are at least ten species of pines scattered over the United States that have serotinous cones; that is to say the cones are sealed by resin; the cone scales do not open and seeds do not disperse until the resin is exposed to high heat (reviewed in Whelan 1995). Examples of fire dependency in herbaceous plants include flowering of wiregrass in Southeastern longleaf pine forests that is greatly enhanced by growing season burns (Myers 1990) and seed germination of California chaparral forbs that is triggered by exposure to smoke (Keeley and Fotheringham 1997). Animals as diverse as rare Karner blue butterflies in Indiana (Kwilosz and Knutson 1999) to whooping cranes in Texas (Chavez Ramirez and others 1996) benefit when fire is re-introduced into their habitats. There are numerous other types of fire dependency in North American ecosystems and many studies on this topic are summarized in books and government publications (e.g. Agee 1993, Bond and van Wilgen 1996, Brown and Kapler Smith 2000, Johnson 1992, Kapler Smith 2000, Wade and others 1980, Whelan 1995). In addition, there is a small but growing volume of literature that evaluates the influence of fire on multiple trophic levels (e.g. Hermann and others 1998).

Knowledge of fire history, fire regimes, and fire effects allows land stewards to develop informed management strategies. Application of fire may be one of the tools used to meet resource management objectives. The role of fire as an important disturbance process has been highlighted in a classification of continental fire regimes (Kilgore and Heinselman 1990). These authors describe a natural fire regime as the total pattern of fires over time that is characteristic of a region or ecosystem. Fire regimes are defined in terms of fire type and severity, typical fire sizes and patterns, and fire frequency, or length of return intervals in years. Kilgore and Heinselman (1990) placed natural fire regimes of North America into seven classes, ranging from Class 0, in which fires are rare or absent, to Class 6, in which crown fires and severe surface fires occur at return intervals longer than 300 years. Intermediate fire regimes, Classes 1-5, are characterized by increasingly longer fire return intervals and increasingly higher fire intensities. Class 2, for example, describes the situation for long-needled pines, like longleaf pine, ponderosa pine, and Jeffrey pine; in this class low severity, surface fires occur rather frequently (return intervals of less than 25 years). Lodgepole pine, jackpine, and the boreal forest of Canada and Alaska generally fall into Class 4, a class in which high severity crown fires occur every 25 to 100 years; or into Class 5, a class in which crown fires occur every 100 to 300 years. White bark pine forests at high elevations typically fall into Class 6. For comparison, three general classes of fire are shown in figure 2.1, including a low-intensity surface fire, a mixed-severity fire, and a stand-replacing crown fire.

Figure 2.1. The relative difference in general classes of fire are shown. This series illustrates a low-intensity surface fire (a), a mixed-severity fire (b), and a stand-replacing crown fire (c).

A noteworthy aspect of continental fire regimes is that very few North American ecosystems fall into Class 0. In other words, most ecosystems in the United States have evolved under the consistent influence of wildland fire, establishing fire as a process that affects numerous ecosystem functions described earlier. Those who apply prescribed burns or use wildland fire often attempt to mimic the natural role of fire in creating or maintaining ecosystems. Sustaining the productivity of fire-adapted ecosystems generally requires application of prescribed fire on a sufficiently large scale to ensure that various ecosystem processes remain intact.

Ecological Effects of Altered Fire Regimes

As humans alter fire frequency and severity, many plant and animal communities experience a loss of species diversity, site degradation, and increases in the sizes and severity of wildfires. Ferry and others (1995) concluded that altered fire regimes was the principal agent of change affecting vegetative structure, composition, and biological diversity of five major plant communities totaling over 350 million acres in the U.S. As a way to evaluate the current amount of fire in wildland habitat, Leenhouts (1998) compared estimated land area burned 200-400 years ago ("pre-industrial") to data from the contemporary conterminous United States. The result suggests that ten times more acreage burned annually in the pre-industrial era than does in modern times. After accounting for loss of wildland area due to land use changes such as urbanization and agriculture, Leenhouts concluded that the remaining wildland is burned approximately fifty percent less compared to fire frequency under historical fire regimes (figure 2.2).

Numerous ecosystem indicators serve as alarming examples of the effects of altered fire regimes. Land use changes, attempted fire exclusion practices, prolonged drought, and epidemic levels of insects and diseases have coincided to produce extensive forest mortality, or major changes in forest density and species composition. Gray (1992) called attention to a forest health emergency in parts of the western

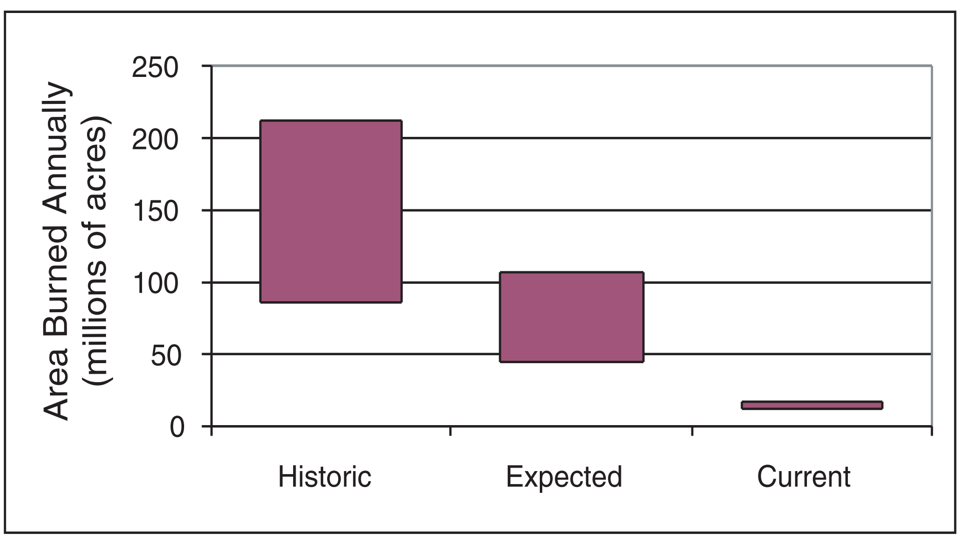

Figure 2.2. Estimates of the range of annual area burned in the conterminous United States pre-European settlement (Historic), applying presettlement fire frequencies to present land cover types (Expected), and burning (wildland and agriculture) that has occurred during the recent past (Current). Source: Leenhouts (1998).

United States where trees have been killed across millions of acres in eastern Oregon and Washington. He indicated that similar problems extend south into Utah, Nevada, and California, and east into Idaho. Denser stands and heavy fuel accumulations are also setting the stage for high severity crown fires in Montana, Colorado, Arizona, New Mexico, and Nebraska, where the historical norm in long-needled pine forests was for more frequent low severity surface fires (fire regime Class 2; Kilgore and Heinselman 1990). The paired photos in figure 2.3 illustrate 85 years of change resulting from fire exclusion on a fire-dependent site in western Montana. In North Carolina, Gilliam and Platt (1999) quantified the dramatic effects of over 80-years of fire exclusion on tree species composition and stand structure in a longleaf pine forest.

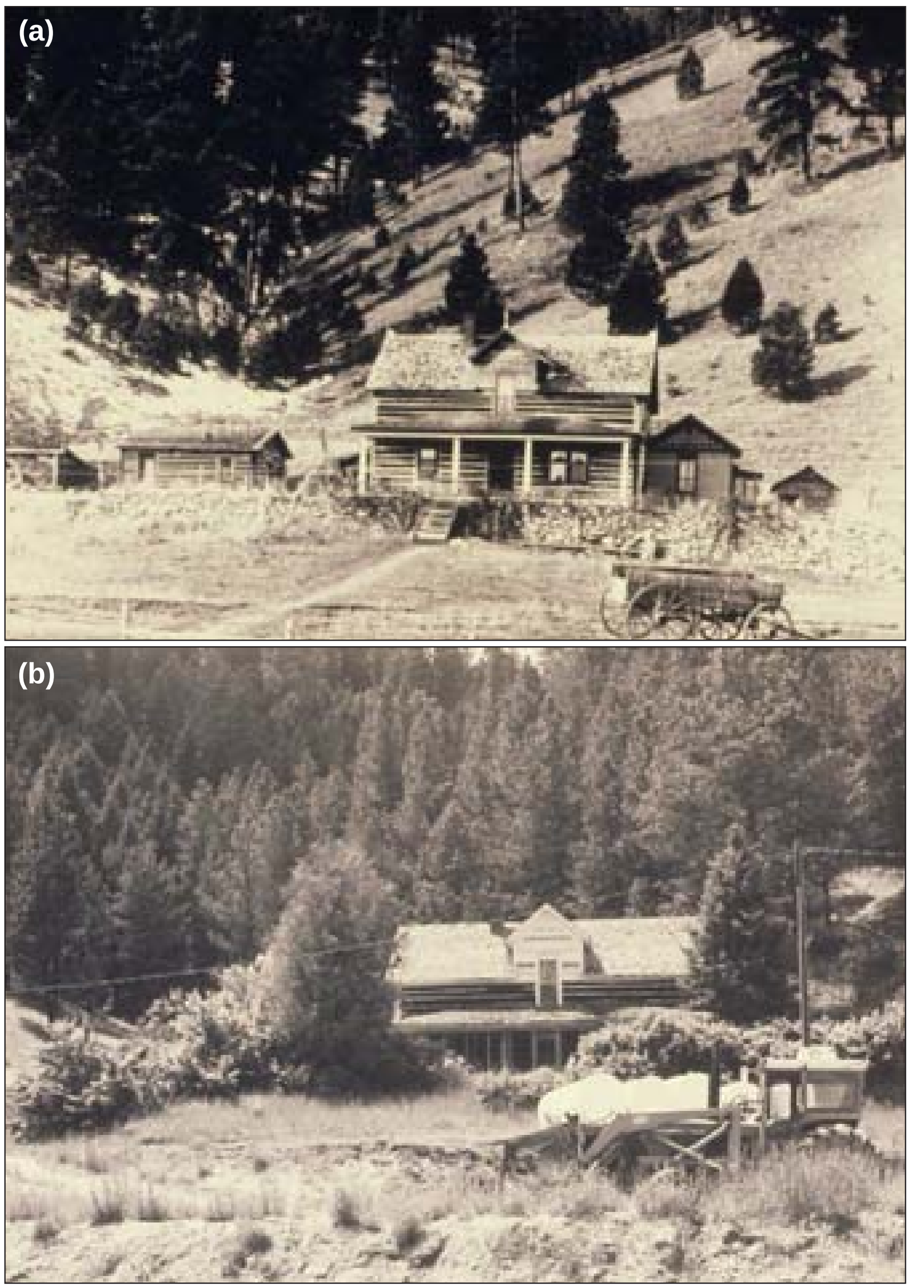

Figure 2.3. These two photos, taken of the same homestead near Sula, Montana, show 85 years of change on a fire-dependent site where fire has been excluded. The top photo (a) was taken in 1895. By 1980 (b), encroaching trees and shrubs occupy nearly all of the site. Stand-replacing crown fire visited this site in 2000.

Since the 1960s, records show an alarming trend towards more acres consumed by wild fires, despite all of our advances in fire suppression technology (figure 2.4). The larger, more severe wildfires have accelerated the rate of tree mortality, threatening people, property, and natural resources (Mutch 1994). These wildfires also have emitted large amounts of particulate matter into the atmosphere. One study estimated that more than 53 million pounds of respirable particulate matter were produced over a 58-day period by the 1987 Silver Fire in southwestern Oregon (Hardy and others 1992).

The ecological consequences of past policies of fire exclusion have been foreseen for some time. More than 50 years ago, Weaver (1943) reported that the "complete prevention of forest fires in the ponderosa pine region of California, Oregon, Washington, northern Idaho, and western Montana has certain undesirable ecological and silvicultural effects [and that]... conditions are already deplorable and are becoming increasingly serious over large areas." Also, Cooper (1961) stated, "…fire has played a major role in shaping the world's grassland and forests. Attempts to eliminate it have introduced problems fully as serious as those created by accidental conflagrations." Only more recently have concerns been expressed about potential loss of biodiversity as a result of fire suppression. This issue may be especially pressing in the Eastern United States. For example, in southern longleaf pine ecosystems, at least 66 rare plant species are maintained by frequent fire (Walker 1993). The ecological need for high fire frequency in large areas of Southeastern native ecosystems coupled with the region's long growing season contribute to the rapid buildup of fuel and subsequent change in habitat structure.

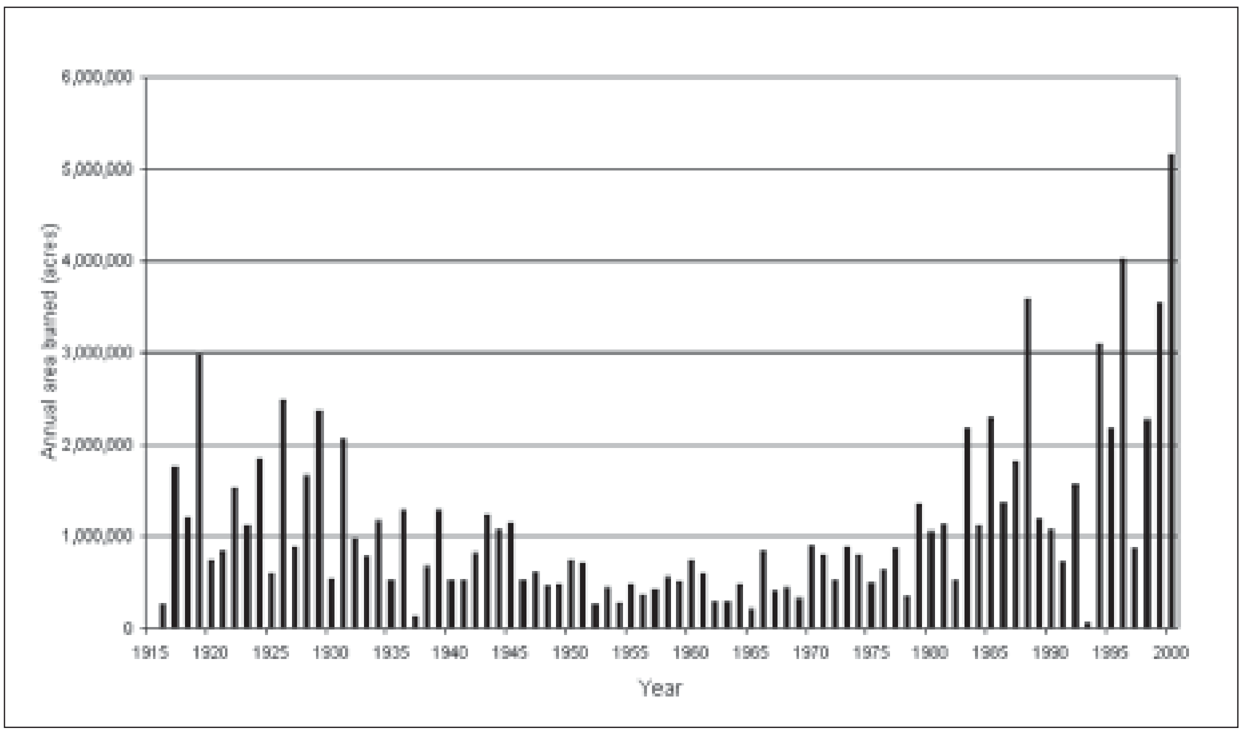

Figure 2.4. The average annual burned area for the western States, shown here for the period 1916-2000, has generally been increasing since the mid-1960s

Wildland and Prescribed Fire Terminology Update

The federal Implementation Procedures Reference Guide for Wildland and Prescribed Fire Management Policy (USDI and USDA Forest Service 1998) contains significant changes in fire terminology. Several traditional terms have either been omitted or have been made obsolete by the new policy. These include: confine/contain/control; escaped fire situation analysis; management ignited prescribed fire; pre-suppression; and prescribed natural fire, or "PNF." Additionally, there was adoption of several new terms and interpretations that supercedes earlier, traditional terminology:

- **Fire Use -** the combination of wildland fire use and prescribed fire application to meet resource objectives.
- **Prescribed Fire -** Any fire ignited by management actions to meet specific objectives. A written, approved prescribed fire plan must exist, and NEPA requirements must be met, prior to ignition. This term replaces management ignited prescribed fire.
- **Wildfire -** An unwanted wildland fire. *This term was only included to give continuing credence to the historic fire prevention products. This is NOT a separate type of fire under the new terminology.*
- **Wildland Fire -** Any non-structure fire, other than prescribed fire, that occurs in the wildland. This term encompasses fires previously called both wildfires and prescribed natural fires.
- **Wildland Fire Use -** the management of naturally-ignited wildland fires to accomplish specific pre-stated resource management objectives in predefined geographic areas outlined in Fire Management Plans. Wildland fire use is not to be confused with "fire use," which is a broader term encompassing more than just wildland fires.

Taking Action: The Federal Wildland and Prescribed Fire Policy

The decline in resiliency and ecological "health" of ecosystems has reached alarming proportions in recent decades, as evidenced by the trend since the mid-1960's towards more acres burned in wildfires (figure 2.4). While national awareness of this trend has existed for some time, the 1994 fire season created a renewed awareness and concern among Federal land management agencies and their constituents regarding the serious impacts of wildfires. The Federal Wildland Fire Management Policy and Program Review is chartered by the Secretaries of Agriculture and Interior to "ensure that uniform federal policies and cohesive interagency and intergovernmental fire management programs exist" (USDI and USDA Forest Service 1995). The review process is directed by an interagency Steering Group whose members represented the Departments of Agriculture and Interior, the U.S. Fire Administration, the National Weather Service, the Federal Emergency Management Agency, and the Environmental Protection Agency. In their cover letter accepting the Final Report of the Review (December 18, 1995), the Secretaries of Agriculture and Interior proclaimed:

> *"The philosophy, as well as the specific policies and recommendations, of the Report continues to move our approach to wildland fire management beyond the traditional realms of fire suppression by further integrating fire into the management of our lands and resources in an ongoing and systematic manner, consistent with public health and environmental*

quality considerations. We strongly support the integration of wildland fire into our land management planning and implementation activities. Managers must learn to use fire as one of the basic tools for accomplishing their resource management objectives."

USDI and USDA Forest Service 1995—cover memorandum

The Report asserts that "the planning, implementation, and monitoring of wildland fire management actions will be done on an interagency basis with the involvement of all partners." The term "partners" is all-encompassing, including Federal land management and regulatory agencies; tribal governments; Department of Defense; State, county, and local governments; the private sector; and the public. Partnerships are essential for establishing collective priorities to facilitate use of fire at the landscape level. Smoke does not respond to artificial boundaries or delineations. Interaction among partners is necessary to meet the dual challenge of using fire for natural resource management coupled with the need to minimize negative effects related to smoke. Both concerns must be met to fulfill the public need.

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The Smoke Management Imperative

Colin C. Hardy
Sharon M. Hermann
John E. Core

Introduction

In the past, smoke from prescribed burning was managed primarily to avoid nuisance conditions objectionable to the public or to avoid traffic hazards caused by smoke drift across roadways. While these objectives are still valid, today's smoke management programs are also likely to be driven, in part, by local, regional and federal air quality regulations. These new demands on smoke management programs have emerged as a result of Federal Clean Air Act requirements that include standards for regulation of regional haze and the recent revisions to the National Ambient Air Quality Standards (NAAQS) on particulate matter.[1]

Development of the additional requirements coincides with renewed efforts to increase use of fire to restore forest ecosystem health. These two requirements are interrelated:

- The purity of the air we breathe is essential to our health and quality of our lives and smoke from wildland and prescribed fire can have adverse effects on public health.
- The national forests, national parks and wilderness areas set aside by Congress are among the nation's greatest treasures. They inspire us as individuals and as a nation. Smoke from wildland burning can obscure these natural wonders.
- Although smoke may be an inconvience under the best conditions and a public health and safety risk under the worst conditions, without periodic fires, the natural habitat that society holds in such high esteem will decline and ultimately dissapear. In addition, as ecosystem health declines, fuel increases to levels that also pose significant risks for wildfire and consequently additional safety risks.
- Wildland and prescribed fire managers are entrusted with balancing these and other, often potentially conflicting responsibilities. Fire managers are charged with the task of increasing the use of fire to accomplish important land stewardship objectives and, at the same time, are entrusted to protect public safety and health.

Purpose of a Smoke Management Program

The purpose of a smoke management program is to:

[1] See Chapter 4, Regulations for Smoke Management, for details on specific requirements.

- minimize the amount of smoke entering populated areas, preventing public health and safety hazards (e.g. visual impairment on roadways or runways) and problems at sensitive sites (e.g. nursing homes or hospitals),
- avoid significant deterioration of air quality and NAAQS violations, and
- eliminate human-caused visibility impacts in Class I areas.

Smoke management programs create a framework of procedures and requirements for managing smoke from prescribed fires and are typically developed by States or tribes with cooperation and participation from stakeholders. Procedures and requirements developed through partnerships are more effective at meeting resource management goals, protecting public health, and achieving air quality objectives than programs that are created in isolation. Sophisticated programs for coordination of burning both within a state and across state boundaries are vital to obtain and maintain public support of burning programs. Fire use professionals are increasingly encouraged to burn at a landscape level. In some cases, when objectives are based in both ecology and fuel reduction, there is a need to consider burning during challenging times of the year (e.g. during the growing season rather than the cooler dormant season). Multiple objectectives for fire use are likely to increase the challenges, consequently increasing the value of partnerships for smoke management.

Smoke management is increasingly recognized as a critical component of a state or tribal air quality program for protecting public health and welfare while still providing for necessary wildland burning.

Usually, either a state or tribal natural resources agency or air quality agency is responsible for developing and administering the smoke management program. Occasionally a smoke management program may be administered by a local agency. California, for example, relies on local area smoke management programs. Generally, on a daily basis the administering agency approves or denies permits for individual burns or burns meeting some criteria. Permits may be required for all fires or only for those that exceed an established de minimis level (which could be based on projections of acres burned, tons consumed, or emissions). Multi-day burns may be subject to daily reassessment and re-approval to ensure compliance with smoke management program goals.

Advanced smoke management programs evaluate individual and multiple burns; coordinate all prescribed fire activities in an area; consider cross-boundary (landscape) impacts; and weigh decisions about fires against possible health, visibility, and nuisance effects. With increasing use of fire for forest health and ecosystem management, interstate and interregional coordination of burning will be necessary to prevent episodes of poor air quality. Development of, and participation in, an effective smoke management program by state agents and land managers will go a long way towards building and maintaining public acceptance of prescribed burning.

The Need for Smoke Management Programs

The call for increasingly effective smoke management programs has occurred because of public and governmental concerns about the possible risks to public health and safety, as well as nuisance and regional haze impacts of smoke from wildland and prescribed fires. There are also concerns about contributions to health-related National Ambient Air Quality Standards. Each of these areas is summarized below.[2]

Public Health Protection: Fine Particle National Ambient Air Quality Standards.– EPA's most recent review of the National Ambient Air Quality Standards for Particulate Matter (PM_{10}) concluded that significant changes were needed to assure the protection of public health. In July of 1997, following an extensive review of the global literature, EPA adopted a fine particle ($PM_{2.5}$) standard.[3]

These small particles are largely responsible for the health effects of greatest concern and for visibility reduction in the form of regional haze. More on EPA's fine particle standard is found elsewhere in this Guide.

The close link between regional haze and the new fine particle National Ambient Air Quality Standards means that smoke from prescribed fire is again at the center of attention for air regulators charged with adopting control strategies to attain the new standards.

Public Safety and Nuisance Issues.–Perhaps the most immediate need for an effective smoke management program is related to smoke drifting across roadways and restricting motorist visibility. Each year, people are killed on the nation's highways because of dust storms, smoke and fog. Wildland and prescribed fire managers must recognize the legal issues related to their professional activities. Special care must be taken in administering the smoke management program to assure that smoke does not obscure roadway or airport visibility. Liability issues vary by state. Some states such as Florida have "right-to-burn" laws that provide some protection for fire use professionals with specific training and certification.

Probably the most common air quality issues facing wildland and prescribed fire managers are those related to public complaints about nuisance smoke. Complaints may be about the odor or soiling effects of smoke, poor visibility, and impaired ability to breathe or other health-related effects. Sometimes complaints come from the fact that some people don't like or are fearful of smoke intruding into their lives. Whatever the reason, fire managers have a responsibility to try to prevent or resolve the issue through smoke management plans that recognize the importance of proper selection of management and burning techniquesand burn scheduling based on meteorological conditions. In additioncommunity public relations and education coupled with pre-burn notification can greatly improve public acceptance of fire management programs.

Visibility Protection.–Haze that obstructs the scenic beauty of the Nation's wildlands and national parks does not respect political boundaries. Any program that is intended to reduce visibility impairment in the nation's parks and wildlands must be based on multi-state cooperative efforts or on national legislation.

In 1999, the U.S. EPA issued regional haze regulations to manage and mitigate visibility impairment from the multitude of regional haze sources.[4] Regional haze regulations call for states to establish goals for improving visibility in Class I national parks and wildernesses and to develop long-term strategies for reducing emissions of air pollutants that cause visibility impairment. Wildland and prescribed fire are some of the sources of regional haze covered by the new rules.

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[2] Details relating to *Public Health effects, Problem and Nuisance Smoke, and Regional Haze* are given in the sections 3.1, 3.3 and 4.1, respectively, of this Guide.

[3] One thousand fine particles of this size could fit into the period at the end of this sentence.

[4] [40 CFR Part 51]

Past Success and Commitment to Future Efforts

It is clearly noted in the preface to the 2001 Smoke Management Guide that conflicts among natural resource needs, fire management, and air quality issues are expected to increase. It is equally important to acknowledge the benefits to air quality resulting from the many successful smoke management efforts in the past two decades.

Since the 1980s, federal, state, tribal, and local land managers have recognized the potential impacts of smoke emissions from their activities. Additionally, they have sponsored and pursued new efforts to learn the principles of smoke management and to develop appropriate smoke management applications. Many early smoke management successes resulted from proactive, voluntary inclusion of smoke management components in many burn plans as early as the mid-1980s.

NWCG and its partners are committed to furthering their leadership role in the quest for new information, technology, and innovative techniques. These 2001 revisions to the Guide are evidence of that commitment.

Chapter 3

SMOKE IMPACTS

Public Health and Exposure to Smoke

John E. Core

Janice L. Peterson

Introduction

The purity of the air we breathe is an important public health issue. Particles of dust, smoke, and soot in the air from many sources, including wildland fire, can cause acute health effects. The effects of smoke range from irritation of the eyes and respiratory tract to more serious disorders including asthma, bronchitis, reduced lung function, and premature death. Airborne particles are respiratory irritants, and high concentrations can cause persistent cough, phlegm, wheezing, and physical discomfort when breathing. Particulate matter can also alter the body's immune system and affect removal of foreign materials from the lung like pollen and bacteria.

This section discusses the effects of air pollution, especially particulate matter, on human health and morbidity. Wildland fire smoke is discussed as one type of air pollution that can be harmful to public health[1].

Human Health Effects of Particulate Matter

Many epidemiological studies have shown statistically significant associations of ambient particulate matter levels with a variety of human health effects, including increased mortality, hospital admissions, respiratory symptoms and illness measured in community surveys (Brauer 1999, Dockery and others 1993, EPA 1997). Health effects from both short-term (usually days) and long-term (usually years) particulate matter exposures have been documented. The consistency of the epidemiological data increases confidence that the results reported in numerous studies justify the increased public health concerns that have prompted EPA to adopt increasingly stringent air quality standards (Federal Register 1997). There remains, however, uncertainty regarding the exact mechanisms that air pollutants trigger to cause the observed health effects (EPA 1996).

Figure 3.1.1 illustrates respiratory pathways that form the human body's natural defenses against polluted air. These pathways can be divided into two systems - the upper airway passage consisting of the nose, nasal passages, mouth and pharynx, and the lower airway passages consisting of the trachea, bronchial tree, and alveoli. While coarse particles (larger than about 5 microns in diameter) are deposited in the upper respiratory system, fine particles (less than 2.5 microns in diameter) can penetrate much deeper into the lungs. These fine particles are deposited in the alveoli where the body's defense mechanisms are ineffective in removing them (Morgan 1989).

[1] Information on the effects of smoke on firefighters and prescribed burn crews can be found in Section 3.4.

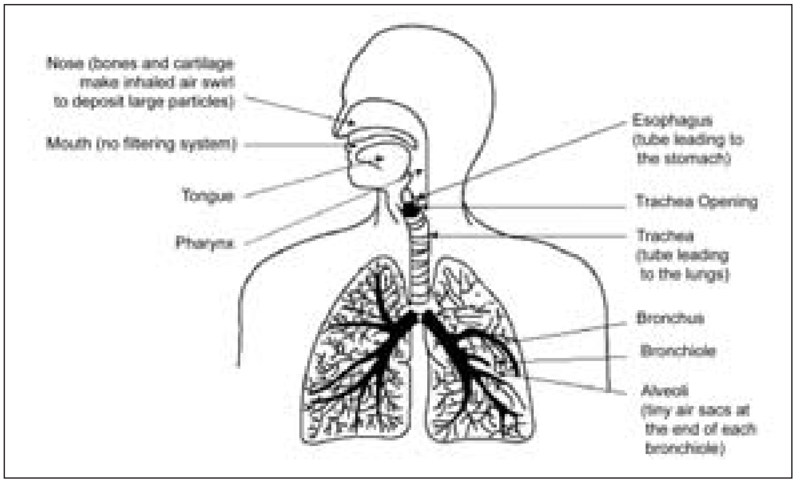

Figure 3.1.1: Particle deposition in the respiratory system.
From: Canadian Center for Occupational Health & Safety, available at http://www.ccohs.ca/oshanswers/ chemicals/how_do.html

On a smoggy day in a major metropolitan area, a single breath of air may contain millions of fine particles. Some 74 million Americans — 28% of the population — are regularly exposed to harmful levels of particulate air pollution (EPA 1997). In recent studies, exposure to fine particles – either alone or in combination with other air pollutants – has been linked with many health problems, including:

- An estimated 40,000 Americans die prematurely each year from respiratory illness and heart attacks that are linked with particulate exposure, especially elderly people (EPA 1997).
- Children and adults experience aggravated asthma. Asthma in children increased 118% between 1980 and 1993, and it is currently the leading cause of child hospital admissions (EPA 1997).
- Children become ill more frequently and experience increased respiratory problems, including difficult and painful breathing (EPA 1997).
- Hospital admissions, emergency room visits and premature deaths increase among adults with heart disease, emphysema, chronic bronchitis, and other heart and lung diseases (EPA 1997).

The susceptibility of individuals to particulate air pollution (including smoke) is affected by many factors. Asthmatics, the elderly, those with cardiopulmonary disease, as well as those with preexisting infectious respiratory disease such as pneumonia may be especially sensitive to smoke exposure. Children and adolescents may also be susceptible to ambient particulate matter effects due to their increased frequency of breathing, resulting in greater respiratory tract deposition. In children, epidemiological studies reveal associations of particulate exposure with increased bronchitis symptoms and small decreases in lung function.

Fine particles showed consistent and statistically significant relationships to short-term mortality in six U.S. cities while coarse particles showed no significant relationship to excess mortality in five of the six cities that were studied (Dockery and others 1993).

Impacts of Wildland Fire Smoke on Public Health

There is not much data which specifically examines the effects of wildland fire smoke on public health, although some studies are planned or underway. We can, however, infer health responses from the documented effects of particulate air pollutants. Eighty to ninety percent of wildfire smoke (by mass) is within the fine particle size class ($PM_{2.5}$), making public exposure to smoke a significant concern.

The Environmental Protection Agency has developed some general public health warnings for specific air pollutants including $PM_{2.5}$ (table 3.1.1) (EPA 1999). The concentrations in table 3.1.1 are 24-hour averages, which can be problematic when dealing with smoke impacts that may be severe for a short period of time and then virtually non-existent soon after. Another guidance document was developed recently to relate short-term, 1-hour averages to the potential human health effects given in table 3.1.1 (Therriault 2001).

Figure 3.1.2 contains these short-term averages plus approximate corresponding visual range in miles. Members of the public can use the methods described to estimate visual range and determine when air quality may be hazardous to their health even if they are located in an area that is not served by an official state air quality monitor.

Figure 3.1.3 is an information sheet developed during a prolonged wildfire smoke episode in Montana during the summer of 2000. The questions and answers address many common concerns voiced by the public during smoke episodes.

Other Pollutants of Concern in Smoke

Although the principal air pollutant of concern is particulate matter, there are literally hundreds of compounds emitted by wildland fires that are found in very low concentrations. Some of these compounds that also deserve mention include:

- Carbon monoxide has well known, serious health effects including dizziness, nausea and impaired mental functions but is usually only of concern when people are in close proximity to a fire (including firefighters). Blood levels of carboxyhemoglobin tend to decline rapidly to normal levels after a brief period free from exposure (Sharkey 1997).
- Benzo(a)pyrene, anthracene, benzene and numerous other components found in smoke from wildland fires can cause headaches, dizziness, nausea, and breathing difficulties. In addition, they are of concern because of long term cancer risks associated with repeated exposure to smoke.
- Acrolein and formaldehyde are eye and upper respriatory irritants to which some segments of the public are especially sensitive.

Table 3.1.1. EPA's pollutant standard index for $PM_{2.5}$ can be used for general assessment of health risks from existing air quality.

Standard Index Category	PM2.5 24-hr concentration ($\mu g/m^3$)	Health Effects	Cautionary Statements
Good	0-15.4	None	None
Moderate	15.5-40.4	None	None
Unhealthy for Sensitive Groups	40.5-65.4	Increasing likelihood of respiratory symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	People with respiratory or heart disease, the elderly and children should limit prolonged exertion.
Unhealthy	65.5-150.4	Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in general population.	People with respiratory or heart disease, the elderly and children should avoid prolonged exertion; everyone else should limit prolonged exertion.
Very Unhealthy	150.5-250.4	Significant aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; significant increase in respiratory effects in general population.	People with respiratory or heart disease, the elderly and children should avoid any outdoor activity; everyone else should avoid prolonged exertion.
Hazardous	>250.4	Serious aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; serious risk of respiratory effects in general population.	Everyone should avoid any outdoor exertion; people with respiratory or heart disease, the elderly and children should remain indoors.

Category	PM2.5 1-hr avg. concentration ($\mu g/m^3$)	Visibility Range (miles)
Good	0-40	10 miles and up
Moderate	41-80	6 to 9 miles
Unhealthy for Sensitive Groups	81-175	3 to 5 miles
Unhealthy	176-300	1 1/2 to 2 1/2 miles
Very Unhealthy	301-500	1 to 1 1/4 mile
Hazardous	Over 500	3/4 mile or less

The procedure for using personal observations to determine the approximate PM_{25} concentration for local areas without official monitors is:

1. Face away from the sun.
2. Determine the limit of your visible range by looking for targets at known distance (miles). Visible range is that point at which even high contrast objects totally disappear.
3. Use the values above to determine the local forest fire smoke category.

Figure 3.1.2. Visibility range can be used by the public to assess air quality in areas with no state air pollution monitors.

Conclusions

The health effects of wildland smoke are of real concern to wildland fire managers, public health officials, air quality regulators and all segments of the public. Fire practitioners have an important responsibility to understand the potential health impacts of fine particulate matter and minimize the public's exposure to smoke.

Wildland fire managers should be aware of sensitive populations and sites that may be affected by prescribed fires, such as medical facilities, schools or nursing homes, and plan burns to minimize the smoke impacts. This is especially true when exposure may be prolonged. Days or weeks of smoke exposure are problematic because the lung's ability to sweep these particles out of the respiratory passages may be suppressed over time. Prolonged exposure may occur as the result of topographic or meteorological conditions that trap smoke in an area. Familiarity with the location and seasonal weather patterns can be invaluable in anticipating and avoiding potential problems while still in the planning phase.

Wildfire Smoke and Your Health

What's in smoke from a wildfire?
Smoke is made up of small particles, gases and water vapor. Water vapor makes up the majority of smoke. The remainder includes carbon monoxide, carbon dioxide, nitrogen oxide, irritant volatile organic compounds, air toxics and very small particles.

Is smoke bad for me?
Yes. It's a good idea to avoid breathing smoke if you can help it. If you are healthy, you usually are not at a major risk from smoke. But there are people who are at risk, including people with heart or lung diseases, such as congestive heart disease, chronic obstructive pulmonary disease, emphysema or asthma. Children and the elderly also are more susceptible.

What can I do to protect myself?

- Many areas report EPA's Air Quality Index for *particulate matter, or PM.* PM (tiny particles) is one of the biggest dangers from smoke. As smoke gets worse, that index changes — and so do guidelines for protecting yourself. So listen to your local air quality reports.
- Use common sense. If it looks smoky outside, that's probably not a good time to go for a run. And it's probably a good time for your children to remain indoors.
- If you're advised to stay indoors, keep your windows and doors closed. Run your air conditioner, if you have one. Keep the fresh air intake closed and the filter clean.
- Help keep particle levels inside lower by avoiding using anything that burns, such as wood stoves and gas stoves – even candles. And don't smoke. That puts even more pollution in your lungs – and those of the people around you.
- If you have asthma, be vigilant about taking your medicines, as prescribed by your doctor. If you're supposed to measure your peak flows, make sure you do so. Call your doctor if your symptoms worsen.

How can I tell when smoke levels are dangerous? I don't live near a monitor.
Generally, the worse the visibility, the worse the smoke. In Montana, the Department of Environmental Quality uses visibility to help you gauge wildfire smoke levels.

How do I know if I'm being affected?
You may have a scratchy throat, cough, irritated sinuses, headaches, runny nose and stinging eyes. Children and people with lung diseases may find it difficult to breathe as deeply or vigorously as usual, and they may cough or feel short of breath. People with diseases such as asthma or chronic bronchitis may find their symptoms worsening.

Should I leave my home because of smoke?
The tiny particles in smoke do get inside your home. If smoke levels are high for a prolonged period of time, these particles can build up indoors. If you have symptoms indoors (coughing, burning eyes, runny nose, etc.), talk with your doctor or call your county health department. This is particularly important for people with heart or respiratory diseases, the elderly and children.

Are the effects of smoke permanent?
Healthy adults generally find that their symptoms (runny noses, coughing, etc.) disappear after the smoke is gone.

Do air filters help?
They do. Indoor air filtration devices with HEPA filters can reduce the levels of particles indoors. Make sure to change your HEPA filter regularly. Don't use an air cleaner that works by generating ozone. That puts more pollution in your home.

Do dust masks help?
Paper "comfort" or "nuisance" masks are designed to trap large dust particles — not the tiny particles found in smoke.

These masks generally will not protect your lungs from wildfire smoke.

How long is the smoke going to last?
That depends on a number of factors, including the number of fires in the area, fire behavior, weather and topography. Smoke also can travel long distances, so fires in other areas can affect smoke levels in your area.

I'm concerned about what the smoke is doing to my animals. What can I do?
The same particles that cause problems for people may cause some problems for animals. Don't force your animals to run or work in smoky conditions. Contact your veterinarian or county extension office for more information.

***How* does smoke harm my health?**
One of the biggest dangers of smoke comes from *particulate matter* — solid particles and liquid droplets found in air. In smoke, these particles often are very tiny, smaller than 2.5 micrometers in diameter. How small is that? Think of this: the diameter of the average human hair is about 30 times bigger.
These particles can build up in your respiratory system, causing a number of health problems, including burning eyes, runny noses and illnesses such as bronchitis. The particles also can aggravate heart and lung diseases, such as congestive heart failure, chronic obstructive pulmonary disease, emphysema and asthma.

What about firefighters?
Firefighters do experience short-term effects of smoke, such as stinging, watery eyes, coughing and runny noses. Firefighters must be in good physical condition, which helps to offset adverse effects of smoke. In addition to being affected by particles, firefighters can be affected by carbon monoxide from smoke. A recent Forest Service study showed a very small percentage of firefighters working on wildfires were exposed to levels higher than occupational safety limits for carbon monoxide and irritants.

Why can't the firefighters do something about the smoke?
Firefighters first priorities in fighting a fire are, by necessity, protecting lives, protecting homes and containing the wildfire. Sometimes the conditions that are good for keeping the air clear of smoke can be bad for containing fires. A windy day helps smoke disperse, but it can help a fire spread.
Firefighters do try to manage smoke when possible. As they develop their strategies for fighting a fire, firefighters consider fire behavior and weather forecasts, topography and proximity to communities – all factors than can affect smoke.

Why doesn't it seem to be as smoky when firefighters are working on prescribed fires.
Land managers are able to plan for prescribed fires. They get to choose the areas they want to burn, the size of those areas and the weather and wind conditions that must exist before they begin burning. This allows them to control the fire more easily and limit its size. Those choices don't exist with wildfires. In addition, wildfires that start in areas that haven't been managed with prescribed fire often have more fuel, because vegetation in the forest understory has built up, and dead vegetation has not been removed.

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Figure 3.1.3. Public health information developed during the Montana wildfires of 2000.

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Visibility

John E. Core

Introduction

Every year there are over 280 million visitors to our nation's wilderness areas and national parks. Congress has set these special places aside for the enjoyment of all that seek spectacular and inspiring vistas. Unfortunately, many visitors are not able to see the beautiful scenery they expect. During much of the year, a veil of haze often blurs their view. The haze is caused by many sources of both natural and manmade air pollution sources, including wildland fire.

This section describes measures of scenic visibility, the properties of the atmosphere and how these properties are affected by smoke from wildland fires, natural and current visibility conditions, as well as sources that contribute to visibility degradation. This is an important issue to wildland fire practitioners because smoke is of increasing interest to air regulators responsible for solving regional haze problems.

Measures of Visibility Impairment

Visibility is most often thought of in terms of visual range or the furthest distance a person can see a landscape feature. However, visibility is more than ***how far*** one can see; it also encompasses ***how well*** scenic landscape features can be seen and appreciated. Changes in visual range are not proportional to human perception. For example, a five-mile change in visual range can result in a scene change that is either imperceptible or very obvious depending on the baseline visibility conditions. Therefore, a more meaningful visibility index has been adopted. The scale of this index, expressed in deciviews (dv) is linear with respect to perceived visual changes over its entire range, analogous to the decibel scale for sound. A one-deciview change represents a change in scenic quality that would be noticeable to most people regardless of the initial visibility conditions. A deciview of zero is equivalent to clear air while deciviews greater than zero depict proportionally increased visibility impairment (IMPROVE 1994). The more deciviews measured, the greater the impairment, which limits the distance you can see. Finally, extinction in inverse megameters (Mm^{-1}) is proportional to the amount of light lost as it travels through a million meters of atmosphere and is most useful for relating visibility directly to particulate concentrations. Table 3.2.1 compares each of these three forms of measurement (Malm 1999).

Properties of the Atmosphere & Wildland Fire Smoke

An observer sees an image of a distant object because light is reflected from the object along the sight path to the observer's eye. Any of this image-forming light that is removed from the sight path by scattering or light absorption

Visual Range										
(Km)	200	130	100	80	60	40	13	10	8	6
(Miles)	124	81	62	50	37	25	8	6	5	4
Deciviews (dv)	7	11	14	16	19	23	34	37	39	42
Extinction (Mm^{-1})	20	30	40	50	70	100	300	400	500	700

Table 3.2.1. Comparison of the four expressions of visibility measurement.

reduces the image-forming information and thereby diminishes the clarity of the landscape feature. Ambient light is also scattered into the sight path, competing with the image-forming light to reduce the clarity of the object of interest. This "competition" between image-forming light and scattered light is commonly experienced while driving in a snowstorm at night with the car headlights on.

In addition, relative humidity also indirectly affects visibility. Although relative humidity does not by itself cause visibility to be degraded, some particles, especially sulfates, accumulate water from the atmosphere and grow to a size where they are particularly efficient at scattering light. Poor visibility in the eastern states during the summer months is a result of the combination of high sulfate concentrations and high relative humidity.

The sum of scattering and absorption is referred to as atmospheric light extinction. Particles that are responsible for scattering are categorized as primary and secondary where primary sources include smoke from wildland fires and wind-blown dust. Other sources of secondary particles include sulfate and nitrate particles formed in the atmosphere. The closer the particle size is to the wavelength of light, the more effective the particle is in scattering light. As a result, relatively large particles of wind-blown dust are far less efficient in scattering light per unit mass than are the fine particles found in smoke from wildland fires. Finally, an important component of smoke from wildland fires is elemental carbon (also known as soot), which is highly effective in absorbing light within the sight path. This combination of light absorption by elemental carbon and light scattering caused by the very small particles that make up wildland fire smoke explains why emissions from wildland fire play such an important role in visibility impairment.

The effect of regional haze on a Glacier National Park vista is shown in the four panels of figure 3.2.1. The view is of the Garden Wall from across Lake McDonald. Particulate concentrations associated with these photographs correspond to 7.6, 12.0, 21.7 and 65.3 $\mu g/m^3$, respectively (Malm 1999). Note the loss of color and detail in the mountains as the particulate concentrations increase and visibility decreases.

Figure 3.2.1. The effect of regional haze on a Glacier National Park vista.
Photo courtesy of the National Park Service, Air Resources Division.

Natural Visibility Conditions

Some light extinction occurs naturally due to scattering caused by the molecules that make up the atmosphere. This is called Rayleigh scattering and is the reason why the sky appears blue. But even without the influence of human-caused air pollution, visibility would not always reach the approximately 240-mile limit defined by Rayleigh scattering. Naturally occurring particles, such as windblown dust, smoke from natural fires, volcanic activity, and biogenic emissions (e.g. pollen and gaseous hydrocarbon) also contribute to visibility impairment although the concentrations and sources of some of these particles remain a point of investigation.

Average natural visibility in the eastern U.S. is estimated to be about 60-80 miles (8-11 dv), whereas in the western US it is about 110-115 miles (4.5-5 dv) (Malm 1999). Lower natural visibility in the eastern U.S. is due to higher average humidity. Humidity causes fine particles to stick together, grow in size, and become more efficient at scattering light. Under natural conditions, carbon-based particles are responsible for most of the non-Rayleigh particle-

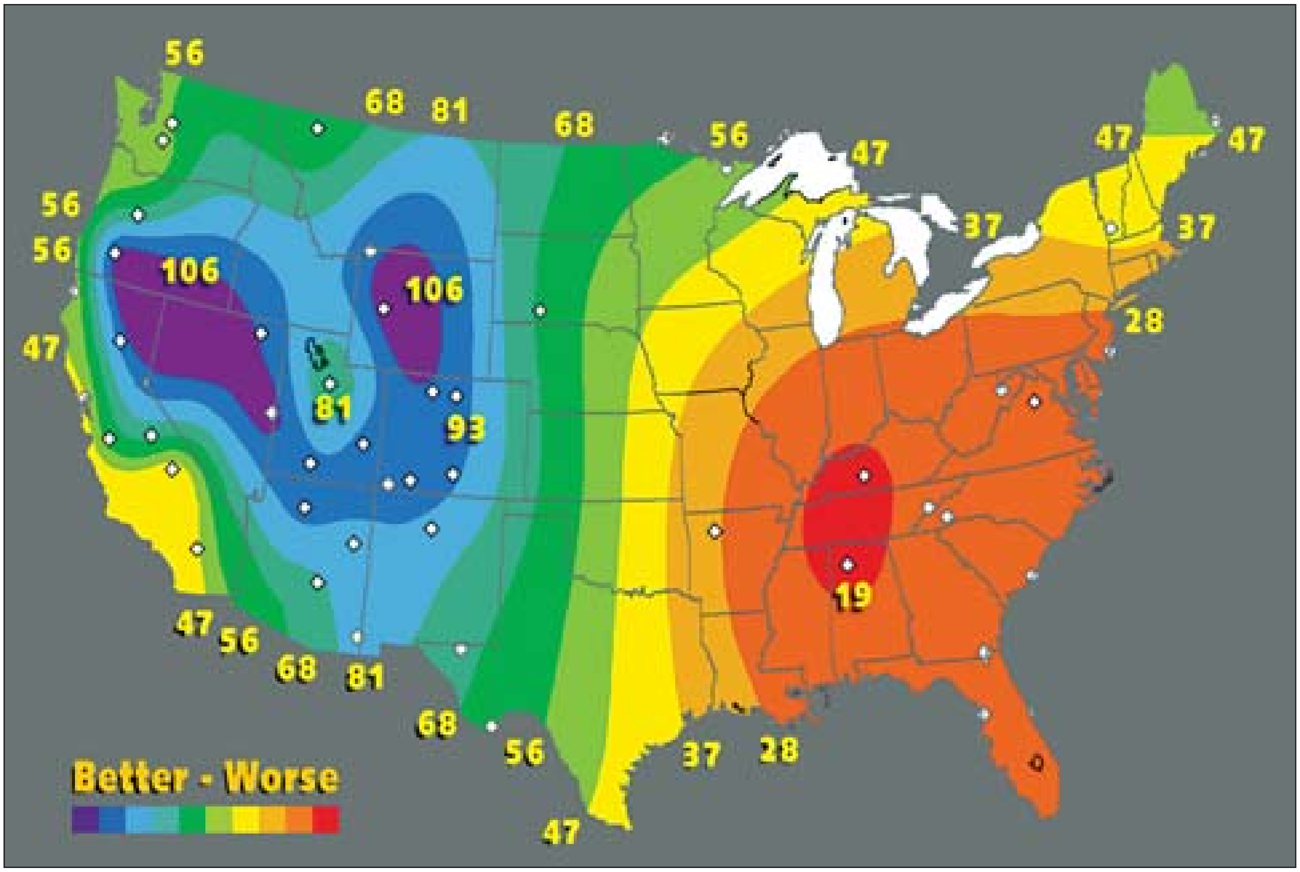

Figure 3.2.2. *Average annual visual range, in miles, for the years 1996-1998 measured at IMPROVE network monitors.*

associated visibility reduction, with all other particle species contributing significantly less. Scattering from naturally occurring sulfate particles from volcanic sulfur dioxide emissions and oceanic sources of primary sulfate particles are estimated to account for 9-12% of the impairment in the East and 5% in the West (NPS 1997). It is expected that coastlines and highly vegetated areas may be lower than these averages, while some elevated areas (mountains) could exceed these background estimates.

Current Visibility Conditions

Currently, average visual range in the eastern U.S. is about 15-30 miles, or about one-third of the estimated natural background for the East. In the West, visual range currently averages about 60-90 miles, or about one-half of the estimated natural background for the West. Current annual visual range conditions expressed in miles are shown in figure 3.2.2. Notice how much more impaired visibility is in the East versus the West.

In the East, 60-70% of the visibility impairment is attributed to sulfates. Sulfate particles form from sulfur dioxide gas, most of which is released from coal-burning power plants and other industrial sources such as smelters, industrial boilers, and oil refineries. Carbon-based particles contribute about 20% of the impairment in the East. Sources of organic carbon particles include vehicle exhaust, vehicle refueling, solvent evaporation, food cooking, and fires.

Elemental carbon particles (or light absorbing carbon) are emitted by virtually all combustion activities, but are especially prevalent in diesel exhaust and smoke from wood burning.

In the West, sulfates contribute less than 30% (Oregon, Idaho and Nevada) to 40-50% (Arizona, New Mexico and Southwest Texas) of light extinction. Carbon particles in the West are a greater percentage of the extinction budget ranging from 50% or greater in the Northwest to 30-40% in the other western regions. The higher percentages of the extinction budget associated with carbon particles in the West appear to be from smoke emitted by wildland and agricultural fires (NPS 1994).

In summary, the physics of light extinction in the atmosphere coupled with the chemical composition and physical size distribution of particles in wildland fire smoke combine to make fire (especially in the West) an important contributor to visibility impairment. Wildland fire managers responsible for the protection of the scenic vistas of this nation's wilderness areas and national parks have a difficult challenge in balancing the need to protect visibility with the need to use fire for other resource management goals.

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Problem and Nuisance Smoke

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Introduction

The particulate matter (or particles) produced from wildland fires can be a nuisance or safety hazard to people who come in contact with the smoke – whether the contact is directly through personal exposure, or indirectly through visibility impairment. Nuisance smoke is defined by the US Environmental Protection Agency as the amount of smoke in the ambient air that interferes with a right or privilege common to members of the public, including the use or enjoyment of public or private resources (US EPA 1990).

Although the vast majority of prescribed burns occur without negative smoke impact, wildland fire smoke can be a problem anywhere in the country. Complaints about loss of visibility, odors, and soiling from ash fallout are not unique to any region. Reduced visibility from smoke has caused fatal collisions on highways in several states, from Florida to Oregon. Acrolein (and possibly formaldehyde) in smoke is likely to cause eye and nose irritation for distances up to a mile from the fire, exacerbating public nuisance conditions (Sandberg and Dost 1990). The abatement of nuisance or problem smoke is one of the most important objectives of any wildland fire smoke management plan (Shelby and Speaker 1990).

This section provides information on the issue of visibility reduction from wildland fire smoke, and focuses particularly on smoke as a major concern in the Southern states. Meteorology, climate and topography combine with population density and fire frequency to make nuisance smoke a chronic issue in the South. Lessons from this regional example can be extrapolated and applied to other parts of the country. This section also briefly summarizes tools currently used or under development to aid the land manager in reducing the problematic effects of smoke.

Wildland fire smoke may also be a nuisance to the public by producing a regional haze, which is discussed in Section 3.2.

Nuisance Smoke and Visibility Reduction

A prescribed fire is a combustion process that has no pollution control devices to remove the pollutants. Instead, prescribed fire practitioners often rely on favorable atmospheric conditions to successfully disperse the smoke away from smoke-sensitive areas, such as communities, areas of heavy vehicle traffic, and scenic vistas. At times, however, unexpected changes in weather (especially wind), or planning which does not adequately factor in such elements as topography, diurnal weather patterns, or residual combustion, may result in an intrusion of smoke that causes negative impacts on the public.

Smoke intrusions and nuisance- or safety-related episodes may happen at any time during the course of a wildland fire, but they frequently occur in valley bottoms and drainages during the night. Within approximately one half hour of sunset, air cools rapidly near the ground, and wind speeds decline as the cooled stable airmass "disconnects" from faster-moving air just above it. High concentrations of smoke accumulate near the ground, particularly smoke from smoldering fuels that don't generate much heat. Smoke then tends to be carried through drainages with little dispersion or dilution. If the drainages are wet, smoke can act as a nucleating agent and can actually assist the formation of local fog, a particular problem in the Southeast. Typically, the greatest fog occurs where smoke accumulates in a low drainage. This can cause hazardous conditions where a drainage crosses a road or bridge, reducing visibility for traffic.

Visibility reduction may also result from the direct impact of the smoke plume. Fine particles (less than 2.5 microns in diameter) of smoke are usually transported to the upper reaches of the atmospheric mixing height, where they are dispersed. They may, however, disperse gradually back to ground level in an unstable atmosphere (figure 3.3.1). When this occurs, such intrusions of smoke can cause numerous nuisance impacts as well as specific safety hazards.

Visibility reduction is used as a metric of smoke intrusions in several State smoke management programs. The State of Oregon program operational guidance defines a "moderately" intense intrusion as a reduction of visibility from 4.6 to 11.4 miles from a background visibility of more than 50 miles (Oregon Dept. Forestry 1992). The State of Washington smoke intrusion reporting system uses "slightly visible, noticeable impact on visibility, or excessive impact on visibility" to define light, medium and heavy intrusions (Washington Dept. Natural Resources 1993). The New Mexico program requires that visibility impacts of smoke be considered in development of the unit's burn prescription (New Mexico Environmental Improvement Board 1995).

Smoke plume-related visibility degradation in urban and rural communities is not subject to regulation under the Clean Air Act. Nuisance smoke is usually regulated under state and local laws and is frequently based on either public complaint or compromise of highway safety (Eshee 1995). Public outcry regarding nuisance smoke often occurs before smoke exposures reach levels that violate National Ambient Air Quality Standards. The Courts have ruled that the taking of private property by interfering with its use and enjoyment caused by smoke without just compensation is in violation of federal constitutional provisions under the Fifth Amendment. The trespass of smoke may diminish the value of the property, resulting in losses to the owner (Supreme Court of Iowa 1998).

Smoke as a Southern Problem

The Forest Atlas of the United States (figure 3.3.2) shows that the thirteen Southern states contain approximately 40% of U.S. forests – about 200 million acres. While not all of this forested land is regularly burned, the extensive forest type generally known as "southern pines" burns with a high fire frequency, about every 2-5 years. When shrublands and grasslands are added to the total, from four to six million acres of southern wildlands are subjected to pre-

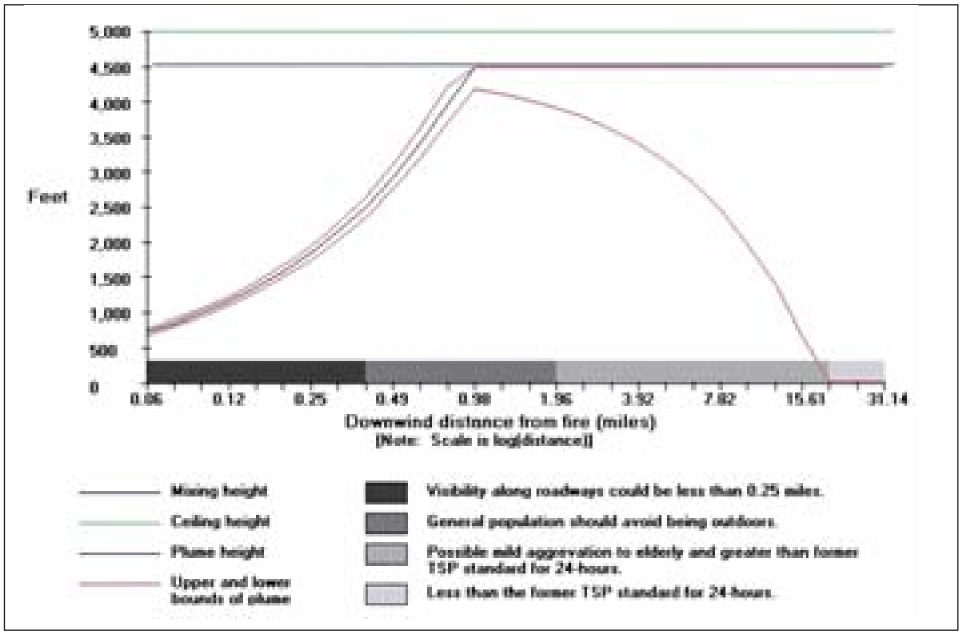

Figure 3.3.1. Graphic from the dispersion model VSmoke-GIS, showing the rise and descent of a smoke plume during a daytime prescribed fire, assuming 25% of the smoke disperses at ground level.

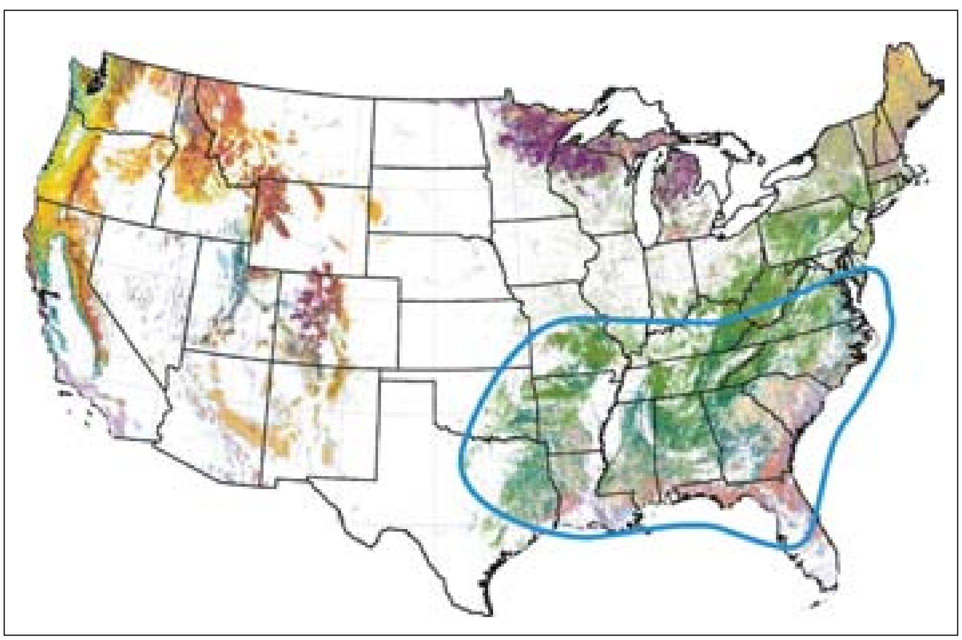

Figure 3.3.2. National Atlas of Forest Cover Types. Southern forests (outlined in blue extend from Virginia to Texas and from the Ohio River southward and account for approximately 40% of U.S. forest land.

scribed fire each year. This is by far the largest acreage of wildlland subjected to prescribed fire in any region of the country.

Figure 3.3.3 shows the 1998 Population Density Classes for the United States. Of particular importance regarding problem smoke is the class "Wildland/Urban Interface," designated in red. A comparison with figure 3.3.2 shows that the wildland/urban interface falls within much of the range of Southern forests. Southern forests, with highest treatment intervals of prescribed fire and with the largest acreages subjected to prescribed fire, are connected with human habitation and activity through an enormous wildland/urban interface. The potential exists for significant smoke problems in this region.

Smoke and Southern Climate

Several factors regarding climate add to the smoke problem in the South. The long growing season allows time for more annual biomass production relative to other areas of the country with shorter growing seasons. Most of the Southern forests are located farther south than forests elsewhere in the country. Consequently, the sun angle is higher in the South and is capable of supplying warmth well into the late fall and early winter. Further, most southern wildlands are located at low elevations where the air is warmer. These factors contribute to the long growing season, which runs from March/April through October/November.

Abundant rainfall also encourages growth of a large number of grasses, shrubs, and trees. Most of the South receives 40-60 inches (100-150 cm) of precipitation annually. This copious rainfall, in combination with the long growing season, creates conditions for rapid buildup of both dead and live fuels. If burns are not conducted frequently, the increase in emissions from the accumulated fuels may enhance the likelihood of negative smoke impacts when fires do occur.

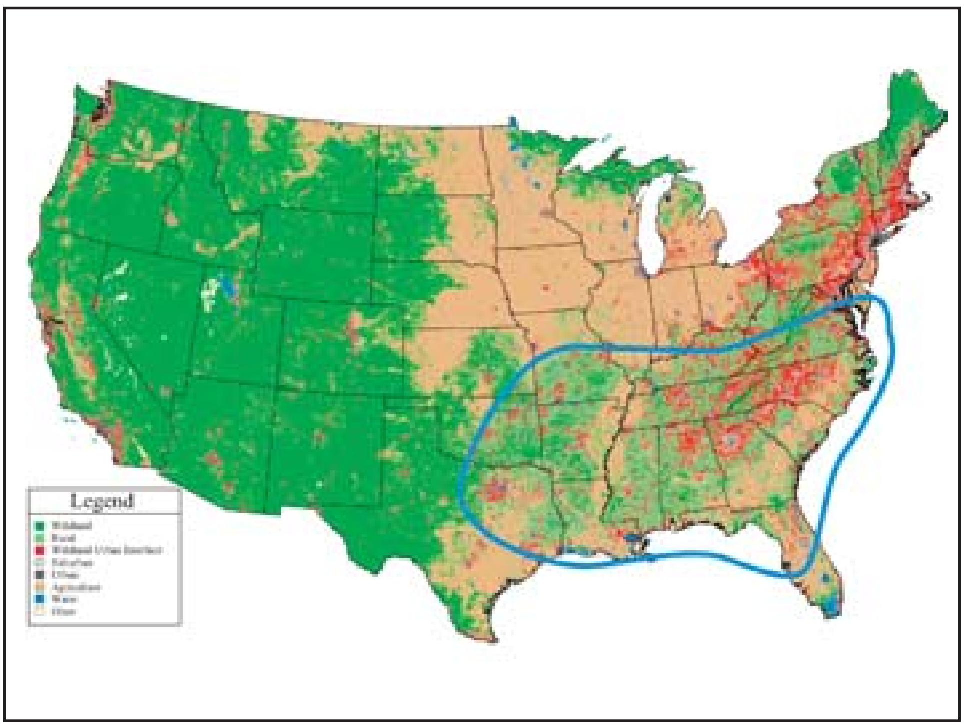

Figure 3.3.3. Population density classes showing wildland/urban interface in red. Southern forests outlined in blue. [http://www.fs.fed.us/fire/fuelman]

The coincidence of dormant-season burning with the winter rain season is a third factor contributing to nuisance smoke. Although burning is conducted year round throughout the South, a significant amount of burning is done during January through March. In a typical year, anywhere from 10-20 inches (25-50 cm) of rain will fall over Southern forests during this three-month period. In some areas of the country, the question might be, "Is it wet enough to burn?" In the South, the question is commonly, "Is it dry enough to burn?" Fires burning into moist fuel burn less efficiently and smolder longer than fires burning dry fuels. Both factors increase smoke production. In addition, less heat is produced during inefficient combustion and smoldering. Therefore, more smoke stays near the ground and increases the risk of problem smoke.

Smoke and Southern Meteorology

All thirteen Southern states have implemented burning regulations designed to limit open burning to those days when burning is considered "safe" and the risks of fire escapes are minimal. Many have implemented smoke management regulations. The need to conduct burning in a manner to reduce impacts on air quality over sensitive targets has encouraged "best practice" approaches to open burning.

Efforts to avoid smoke incursions over sensitive targets are often complicated by the highly variable meteorology of Southern weather systems during the extensive burn season. Four weather features that cause frequent wind shifts and may be accompanied by rapid changes in air mass stability and mixing height are described below.

1. Synoptic scale high- and low-pressure systems and accompanying fronts frequent the South during the winter burn season. In a typical sequence of events, the winds shift to blow from the southeast through southwest in advance of a storm, then shift rapidly to the northwest with cold front passage. Winds blow from the northwest for a day or so but gradually diminish with the approach of a high pressure system, becoming light and variable as the system passes. Then winds shift back to southerly in advance of the next storm. Low clouds, low mixing heights, and high stability often accompany low-pressure systems. Depending upon moisture availability, cold fronts may be accompanied by bands of low clouds and precipitation. Mixing heights are more favorable during high-pressure episodes. Although the movement of synoptic scale weather systems into the South can be predicted with lead times of several days, the timing of arrival of frontal wind shifts over specific burn sites is less certain.

2. Much of the Piedmont and Coastal Plain are flat and it would be expected that winds there are steady and predictable. However, the region is frequented by transient eddies that can cause unexpected wind shifts and carry smoke into sensitive areas. The vertical circulation of air that can force smoke plumes to the ground or carry smoke safely upward are well-understood, but the location, timing and strength of the vertical eddies cannot be predicted. Horizontal eddies have not been well documented, and the timing, location and intensity cannot be predicted.

3. The South has the longest coastline of any fire-prone area in the country. Thus it is axiomatic that large areas of the South are

subject to wind shifts brought on by sea breezes during the day and by land breezes during the night. However, the onset, duration, and intensity of these land/water-induced circulations are not consistent from one day to the next. The region is subject at different times to warm, humid airmasses drawn northward from the Gulf of Mexico, or cold, dry airmasses drawn southward from Canada. Both systems have an impact on land surface temperatures, which results in a significant effect on the duration and extent of land and sea breezes and whether they form at all. The unpredictability of these wind systems adds to the difficulties faced by Southern land managers planning whether smoke from a prescribed burn might impact downwind sensitive targets.

4. The "flying wedge," a wind system caused by cold air channeled southwestward along the eastern slopes of the Appalachian Mountains, can cause sudden wind shifts with large changes in wind direction and lowering of mixing heights. Although Virginia, the Carolinas and Georgia are most frequently impacted, flying wedges have been observed as far south as central Florida and as far west as the Mississippi River. "Flying wedges" occur throughout the year but are most intense, and hence bring with them strong shifting winds and lowering of mixing heights, during winter and early spring, the period of maximum wildland burning in the South.

Smoke and Southern Highways

As previously noted, several million acres of Southern wildlands are burned each year, the vast majority without incident. However, smoke and smoke-induced fog obstructions of visibility on highways sometimes cause accidents with loss of life and personal injuries. Several attempts to compile records of smoke-implicated highway accidents have been made. For the 10-year period from 1979-1988, Mobley (1989) reported 28 fatalities, over 60 serious injuries, numerous minor injuries and millions of dollars in lawsuits. During 2000, smoke from wildfires drifting across Interstate 10 caused at least 10 fatalities, five in Florida and five in Mississippi. In their study of the relationship between fog and highway accidents in Florida, Lavdas and Achtemeier (1995) compared three years of accident reports that mentioned fog with fog reports at nearby National Weather Service stations. Highway accidents were more likely to be associated with local ground radiation fogs than with widespread advection fogs. Accidents tended to happen when fog created conditions of sudden and unexpected changes in visibility.

There are several reasons why smoke on the highways is a serious problem in the South, some of them interrelated.

Road density: The density of the road network in the South is far greater than in other wildland areas in the country where prescribed fire is in widespread use. The difference in road density between generally forested areas in the west and in the south exists primarily because of land use history. While Western forested lands have always been in forest, in the Southern area, roads and communities remain essentially unchanged from the old agricultural South.

Population in wildland areas: The population dwelling near or within Southern wildlands is greater than that in other areas of the country where prescribed fire is in widespread use (figure 3.3.3). Many people live in close proximity to Southern forests; many more live in areas interfacing fire-prone grasslands and shrublands. Southern States are becoming more urban, and the numbers of tourists driving to resort areas along the Gulf coast, the Atlantic coast, and the Florida peninsula are increasing. Therefore, the number of accidents related to smoke and fog can only be expected to increase.

Climate and meteorology: Factors of Southern climate and meteorology combine to produce airmasses that entrap smoke close to the ground at night. Smoke is most often trapped by either a surface inversion or inversion aloft. This is a condition in which temperature increases with height through a layer of the atmosphere. Vertical motion is restricted in this very stable air mass. Although most inversions dissipate with daytime heating, inversions aloft caused by large-scale subsidence may persist for several days, resulting in a prolonged smoke management problem

Most smoke-related highway accidents occur just before sunrise when temperatures are coldest and smoke entrapment has maximized under a surface-level inversion. The high sun angle during the burn season contributes to warm daytime temperatures. Near sunset, under clear skies and near calm winds, temperatures in shallow stream basins can drop up to 20 degrees F. in one hour (Achtemeier 1993). Smoke from smoldering heavy fuels can be entrapped near the ground and carried by local drainage winds into these shallow basins where temperatures are colder and relative humidities are higher. Hygroscopic particles within smoke can assist in development of local dense fog. Weak drainage winds of approximately 1 mile per hour (0.5 m/sec) can carry smoke over 10 miles during the night—far enough in many areas to carry the smoke or fog over a roadway.

Problem Smoke: What is being done to Minimize the Problem

As population growth in the South continues, there is an increasing likelihood that more people will be adversely impacted by smoke. Unless methods are found to mitigate the impacts of smoke, increasingly restrictive regulations may curtail the use of prescribed fire, or fire as a management tool may be prohibited. Several approaches are underway to reduce the uncertainty in predicting smoke movement.

- Several states have devised smoke management guidelines to regulate the amount of smoke put into the atmosphere from prescribed burning. The South Carolina Forestry Commission (1998) has established guidelines to define smoke sensitive areas, amounts of vegetative debris that may be burned, and atmospheric conditions suitable for burning this debris.

- The Forestry Weather Interpretation System (FWIS) was developed by the U.S. Forest Service in the late 1970's and early 1980's in cooperation with the southern forestry community (Paul 1981; Paul and Clayton 1978). The system has been enhanced and automated by the Georgia Forestry Commission (Paul et al. 2000) to serve forestry sources in Georgia and clients in other southern states. The GFC provides weather information and forecasts specified for forest districts, and indices used for interpretations for smoke management, prescribed fire, fire danger, and fire behavior. Indices include the Keetch-Byram Drought Index, National Fire Danger Rating System, Ignition component, Burning Index, and Manning Class Day.

- High resolution weather prediction models promise to provide increased accuracy in predictions of wind speeds and directions and mixing heights at time and spatial scales useful for land managers. The Florida Division of Forestry (FDOF) is a leader in the use of high resolution modeling for forestry applications in the South (Brackett et al. 1997). Accurate predictions of sea/land breezes and associated changes in temperature, wind direction, atmospheric stability and mixing height are critical to the success of the FDOF system as much of Florida is located within 20 miles of a coastline. High resolution modeling consortia are also being established by the U.S. Forest Service to serve clients with interests as diverse as fire weather, air quality, oceanography, ecology, and meteorology.
- Several smoke models are in operation or are being developed to predict smoke movement over Southern landscapes. VSMOKE (Lavdas 1996), a Gaussian plume model that assumes level terrain and unchanging winds, predicts smoke movement and concentration during the day. VSMOKE is now part of the FDOF fire and smoke prediction system. It is a screening model that aids land managers in assessing where smoke might impact sensitive targets as part of planning for prescribed burns. PB-Piedmont (Achtemeier 2001) is a wind and smoke model designed to simulate smoke movement near the ground under entrapment conditions at night. The smoke plume is simulated as an ensemble of particles that are transported by local winds over complex terrain characteristic of the shallow (30-50 m) interlocking ridge/valley systems typical of the Piedmont of the South. PB-Piedmont does not predict smoke concentrations as emissions from smoldering combustion are usually not known. Two sister models are planned, one that will simulate near ground smoke movement near coastal areas influenced by sea/land circulations and the other for the Appalachian mountains.

In summary, the enormous wildland/urban interface and dense road network located in a region where up to six million acres of wildlands per year are subject to prescribed fire combine to make problem smoke the foremost land management-related air quality problem in the South. During the daytime, smoke becomes a problem when it drifts into areas of human habitation. At night, smoke can become entrapped near the ground and, in combination with fog, create visibility reductions that cause roadway accidents. Public outcry regarding problem smoke usually occurs before smoke exposures increase to levels that violate air quality standards. With careful planning and knowledge of local conditions, the fire manager can usually avoid problematic smoke intrusions on the public.

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Smoke Exposure Among Fireline Personnel

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Timothy R. Reinhardt

Wildland firefighting presents many hazards to fireline workers, including inhalation exposure to smoke (Sharkey 1998; Reinhardt and Ottmar 1997; Sharkey 1997). Many experienced fireline personnel consider this to be only an inconvenience, occasionally causing acute cases of eye and respiratory irritation, nausea and headache. Others express concern about long-term health impacts, especially when large-scale fires occur in terrain and atmospheric conditions that force fireline workers to work for many days in smoky conditions. At the present time, no one can say whether there are long-term adverse health effects from occupational smoke exposure. This is because there have been no epidemiological studies to track the health of fireline personnel and compare it with other workers to see if fireline personnel have more or fewer health problems during and after their careers. Until such long-term data are examined to tell us if a problem exists, we can only assess the occurrence of relatively short-term adverse health effects. We can measure fireline worker's exposure to particles and individual chemicals found in smoke and compare these exposures to standards established to protect worker health (Reinhardt and Ottmar 2000; Reinhardt and others 2000; Reinhardt and others 1999). We can evaluate the relative risk of disease among fireline workers based on the exposure data and the potency of the health hazards (Booze and Reinhardt 1996).

Health Hazards in Smoke

Smoke from wildland fires is composed of hundreds of chemicals in gaseous, liquid, and solid forms (Sandberg and Dost 1990; Reinhardt and Ottmar 2000; Reinhardt and others 2000; Sharkey 1998; Sharkey 1997). The chief inhalation hazards for fireline personnel and to the general public when they are exposed to smoke appear to be carbon monoxide and respirable irritants which include particulate matter, acrolein, and formaldehyde.

Carbon Monoxide — Carbon monoxide (CO) has long been known to interfere with the body's ability to transport oxygen. It does this by bonding with hemoglobin, the molecule in the bloodstream which shuttles oxygen from the lungs throughout the body, to form carboxyhemoglobin (COHb). When people are exposed to CO, the time until a toxic level of COHb results can be predicted as a function of CO concentration, breathing rate, altitude, and other factors (Coburn, Forster and Kane 1965). The harder the work and the higher the altitude, the more rapidly COHb forms at a given level of atmospheric CO. At the highest CO levels found in heavy smoke, symptoms of excessive COHb can result in 15 minutes during hard physical labor.

Carbon monoxide causes acute effects ranging from diminished work capacity to nausea, headache, and loss of mental acuity. It has a well-established mechanism of action, causing displacement of oxygen from hemoglobin in the blood and affecting tissues that do not stand the loss of oxygen very well, such as the brain, heart, and unborn children. Fortunately, most of these effects are reversible and CO is rapidly removed from the body, with a half-life on the order of 4 hours. Some studies have linked CO exposure to longer-term heart disease, but the evidence is not clearcut.

Respirable Irritants — Experienced fireline workers can attest to eye, nose and throat irritation at both wildfires and prescribed burns. Burning eyes, runny nose, and scratchy throat are common symptoms in smoky areas at wildland fires, caused by the irritation of mucous membranes. These adverse health effects are symptoms of exposure to aldehydes, including formaldehyde, acrolein, as well as respirable particulate matter ($PM_{2.5}$)—very fine particles less than a few micrometers (μm) in diameter—composed mostly of condensed organic and inorganic carbon (Dost 1991). Other rapid adverse health effects of aldehydes include temporary paralysis of the respiratory tract cilia (microscopic hairs which help to remove dust and bacteria from the respiratory tract) and depression of breathing rates (Kane and Alarie 1977), while over the long term, formaldehyde is considered a potential cause of nasal cancer (U.S. Department of Labor, Occupational Safety and Health Administration 1987).

Adverse health effects of smoke exposure begin with acute, instantaneous eye and respiratory irritation and shortness of breath but can develop into headaches, dizziness and nausea lasting up to several hours. The aldehydes, such as acrolein and formaldehyde, and $PM_{2.5}$ cause rapid minor to severe eye and upper respiratory tract irritation. Total supsended particulate (TSP) also irritates the eyes, upper respiratory tract and mucous membranes, but the larger particulates in TSP do not penetrate as deeply into the lungs as the finer $PM_{2.5}$ particles. Longer-term health effects lasting days to perhaps months have recently been identified among fireline workers, including modest losses of pulmonary function. These include a slightly diminished capacity to breathe, constriction of the repsiratory tract, and hypersensitivity of the small airways (Letts and others 1991; Reh and others 1994).

A discussion of particulate inhalation hazards faced by fireline personnel is incomplete without mentioning crystalline silica, which can be an additional hazard in the presence of smoke. If crystalline silica is a component of the soil at a site, dust stirred up by walking, digging, mop-up, or vehicles may be a significant irritation hazard, and the threat of silicosis (fibrous scarring of the lungs decreasing oxygenation capability) is a possibility.

Evaluation Criteria

On what basis do we decide whether smoke exposure is safe or unsafe? Workplace exposures to health hazards must be evaluated with care for several reasons. First, people vary in their sensitivity to pollutants. Second, personal habits and physical condition are important factors. For example, smokers already commonly experience 5% COHb because of the CO from their cigarettes, thus they may be at greater risk of adverse health effects from additional CO exposure at fires. Assumptions are made by regulatory agencies when establishing exposure limits. These assumptions may not be valid for the wildland fire workplace. For example, the current CO standard was set to protect a sedentary worker in an 8-hour per day job over a working lifetime, not a hard-working fireline worker on a 12-hour/day job for a few summers.

Given these issues, how should we judge the safety of smoke exposure? At a minimum, a fireline worker's inhalation exposures must comply with the occupational exposure limits, called "Permissible Exposure Limits" (PEL's), by the Occupational Safety and Health Administration (OSHA) (U.S. Department of Labor, Occupational Safety and Health Administration 1994). These limits are set at levels considered feasible to attain, and necessary to protect most workers from adverse health effects over their working lifetime. The more stringent exposure limits recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) are the "Threshold Limit Values" (TLVs) (American Conference of Governmental Industrial Hygienists 2000). These are also established to prevent adverse health effects in most workers, but without adjustment for economic feasibility. The ACGIH limits are periodically updated to incorporate the latest scientific knowledge where as many of the PEL's have not been revised since the 1960's. All exposure limits are expressed in terms of a time-weighted average (TWA) exposure, which is an average exposure over the workshift. For health hazards which quickly cause adverse effects from acute exposures, the limits are supplemented by short-term exposure limits (STELs) for 15-minute periods in a workshift and ceiling exposure limits (C), which are not to be exceeded at any time. These various exposure limits are listed in table 3.4.1, along with a third set of "Recommended Exposure Limits" established by the National Institute for Occupational Safety and Health; these also incorporate recent scientific evidence. Depending on the pollutant, the units of measure are either milligrams per cubic meter of air (mg/m^3) or parts per million by volume (ppm). Without a more detailed analysis of a given work/rest regime, adhering to the ACGIH TLV limits should provide reasonable protection for workers.

Table 3.4.1. Occupational exposure limits[a]

Organization	Acrolein (ppm)	Benzene (ppm)	CO (ppm)	HCHO (ppm)	Respirable particulate (mg/m^3)
OSHA Permissible Exposure Limit	0.1 TWA	1.0 TWA 5.0 STEL-C	50 TWA	0.75 TWA 2.0 STEL	5.0 TWA
NIOSH Recommended Exposure Limit	0.1 TWA 0.3 STEL	0.1 TWA 1.0 STEL-C	35 TWA 200 STEL-C	0.016 TWA 0.1 STEL-C	N/A
ACGIH Threshold Limit Value	0.1 C (Skin)	0.5 TWA 2.5 STEL (Skin)	25 TWA	0.3 TWA-C	3.0 TWA

[a] **TWA**: Time Weighted Average; **TWA-C**: Time Weighted Average Ceiling Exposure Limit; **STEL**: Short Term Exposure Limit; **TEL-C**: Short Term Exposure Ceiling Limit; **C**: Ceiling Limit; **N/A**: Not Applicable; **(Skin)** Potential skin contact with vapors or liquid should be considered as well.

Smoke Exposure at Prescribed Burns and Wildfires

Several studies (Reinhardt and Ottmar 1997) have evaluated smoke exposure during prescribed burns by obtaining personal exposure samples, which are collected within a foot of a worker's face (the breathing zone) while they are on the job (figure 3.4.1). One study in particular measured smoke exposure among fireline workers at 39 prescribed burns in the Pacific Northwest. The study found that about 10% of firefighter exposures to respiratory irritants and CO exceeded recommended occupational exposure limits (Reinhardt and others 2000) and could pose a hazard. The actual incidence of illness and mortality among wildland fireline workers has not been systematically studied, but short-term adverse health impacts have been observed among fireline personnel at prescribed fires. A study in 1992-93 found small losses in lung function among 76 fireline personnel working at prescribed burns (Betchley and others 1995).

Between 1992 and 1995 a study of smoke exposure and health effects at wildfires in the western United States found results similar to those at prescribed fires. Exposure to carbon monoxide and respiratory irritants exceeded recommended occupational exposure limits for 5 percent of workers (Reinhardt and Ottmar 2000).

At wildfires where fireline workers encounter concentrated smoke, or moderate smoke over longer times, there is a likelihood that many will develop symptoms similar to those seen at prescribed fires. In 1988, engine-based firefighters of the California Department of Forestry and Fire Protection underwent lung function testing before and after the fire season. Small (0.3 to 2%) losses in lung function were observed among the firefighters. These losses

Figure 3.4.1. Bitterroot Hotshot crew member wearing backpack that obtains smoke exposure samples collected within several inches of a worker's face.

were associated with the amount of recent firefighting activity in the study period. The firefighters also reported increased eye and nose irritation and wheezing during the fire season.

Monitoring Smoke Exposure of Fireline workers

During prescribed fire and wildfire exposure studies, it was found that exposure to respiratory irritants could be predicted from measurements of carbon monoxide (Reinhardt and Ottmar 2000). Fire managers and safety officers concerned with smoke exposure among fire crews can use electronic carbon monoxide (CO) monitors to track and prevent overexposure to smoke (figure 3.4.2). Commonly referred to as dosimeters, these lightweight instruments measure the concentration of CO in the air thatfireline personnel breath. Protocols have been developed for sampling smoke exposure among fireline workers with CO dosimeters. These protocols and a basic template have been outlined by Reinhardt and others (1999) for managers and safety officers interested in establishing their own smoke-exposure monitoring program.

Respirator Protection

The Missoula Technology and Development Center (MTDC) has the lead role in studying respiratory protection for fireline workers (Thompson and Sharkey 1966, Sharkey 1997).

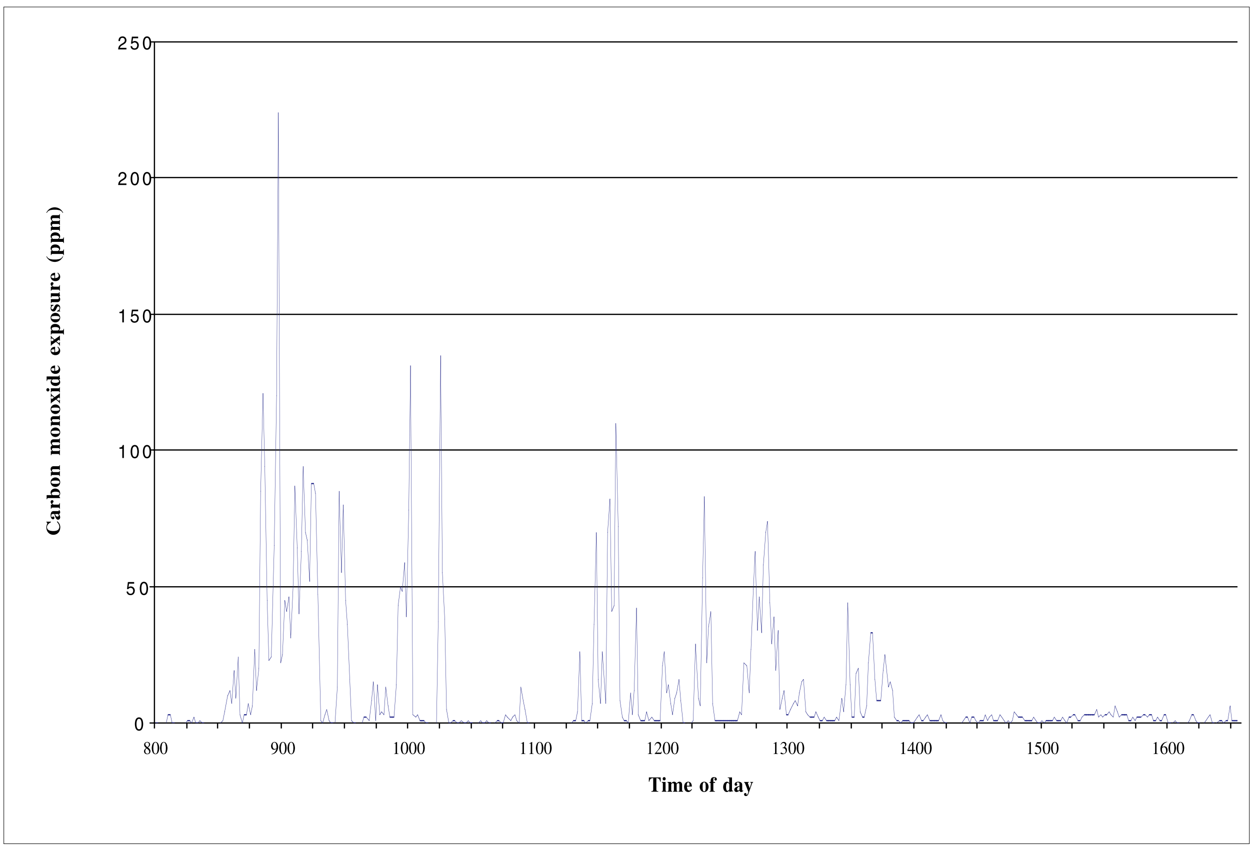

Figure 3.4.2. Carbon monoxide exposure data from a electronic CO data recorder for a fireline worker during a work-shift on a prescribed fire (Reinhardt and others 2000)

Although respirators reduce work capacity, they may have merit under certain circumstances to minimize hazardous exposures. Field evaluations by MTDC found that disposable respirators were acceptable for short-term use but they deteriorated in the heat during several hours of use (Sharkey 1997). Maintenance free half-mask devices were satisfactory, except for the heat stress found with all facemasks. Full-face masks were preferred for the long-term use on prescribed fires because of the eye protection they provided, but workers often complained of headaches, a sign of excess CO exposure since respirators do not eliminate the intake of CO (Sharkey 1997). Full-face respirators protect the eyes, removing eye irritation as an important early warning of exposure to smoke. Any respiratory protection program for fireline workers would require employees to be instructed and trained in the proper use and limitations of the respirators issued to them.

Management Implications

Evidence to date suggests that fireline workers exceed recommended exposure limits during prescribed burns and wildfires less than 10 percent of the time (Reinhardt and others 2000; Reinhardt and Ottmar 2000). The concept that few fireline personnel spend a working lifetime in the fire profession and should be exempt from occupational exposure standards which are set to protect workers over their careers is little comfort to those who do, and irrelevant for irritants and fast-acting hazards such as CO. Most of the exposure limits that are exceeded are established to prevent acute health effects, such as eye and respiratory irritation, headache, nausea and angina. An exposure standard specifically for fireline workers, and appropriate respiratory protection, needs to be developed. In addition, a long-term program to manage smoke exposure at wildland fires is needed (Sharkey 1997). The program could include: 1) hazard awareness training; 2) implementation of practices to reduce smoke exposure; 3) routine CO monitoring with electronic dosimeters (Reinhardt and others 1999); 4) improved record keeping on accident reports to include separation of smoke related illness among fireline workers and fire camp personnel; and 4) implementing and training for an OSHA-compliant respirator program to protect fireline personnel from respiratory irritants and CO when they must work in smoky conditions.

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