



Forest Fire Smoke Management Policy: Can Prescribed Fire Reduce Subsequent Wildland Fire Emissions?

by

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and

Jay O'Laughlin

The College of Natural Resources Policy Analysis Group (PAG) was established by the Idaho Legislature in 1989 to provide objective analysis of the impacts of natural resource proposals (see Idaho Code § 38-714). The PAG is administered by Steven B. Daley Laursen, Dean, College of Natural Resources.

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About the Policy Analysis Group (PAG)

Role and Mission. The Idaho Legislature created the Policy Analysis Group (or “PAG”) in 1989 as a way for the University of Idaho to provide timely, scientific and objective data and analysis, and analytical and information services, on resource and land use questions of general interest to the people of Idaho. The PAG is a unit of the College of Natural Resources Experiment Station, administered by Steven B. Daley Laursen, Director, and Dean, College of Natural Resources.

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Executive Summary

In much of Idaho and the western United States, current forest vegetation conditions and forest fire frequency and intensity are outside their historic ranges of variability. Many forest ecologists and resource managers agree that more ecologically sustainable conditions could be attained by reintroducing fire into the forest under controlled conditions. Such actions may reduce the long-term risks associated with fires burning in uncontrolled conditions, whether ignited by lightning or human activities.

Smoke emissions are one short-term effect of forest fires. Smoke has adverse effects on human health, affects visibility, and is otherwise a nuisance to humans. Many forest managers agree that using prescribed fire can have less adverse effects on air quality than allowing wildland fires to burn forests under uncontrolled conditions. Smoke and other air pollutants are regulated by a web of interrelated federal and state laws and regulations designed to protect human health and welfare (Figure 1, see page 2).

A policy question arises: Are the laws and regulations that protect air quality flexible enough to allow for increased smoke from prescribed fires in the short-term in order to prevent worse air quality from unplanned wildland fires in the future? Yes, if a state has the appropriate clean air policies and programs in place. Idaho seems to have them. We developed this reply by examining current federal and state policies that address the effects of smoke on air quality. We also analyze alternatives that may reduce the impacts of prescribed fire smoke on air quality.

Air Quality Policies. The federal Clean Air Act is the basis for most air quality regulation nationwide. The U.S. Environmental Protection Agency (EPA) is the federal agency charged with implementing the Clean Air Act.

Although the Clean Air Act is a federal law, the states are responsible for much of its implementation. States develop State Implementation Plans (SIPs) that define and describe customized programs that the state will implement to meet the requirements of the Clean Air Act. The state agency in Idaho responsible for implementing Clean Air Act provisions is the Idaho Department of Environmental Quality (IDEQ).

Particulate matter standards. The EPA sets limits on how much pollution can be in the air through the National Ambient Air Quality Standards (NAAQS). NAAQS have been established for six air

pollutants: particulate matter, sulfur dioxide, nitrogen dioxide, ozone, carbon monoxide, and lead.

Particulate matter (PM₁₀ and PM_{2.5}) is the primary pollutant of concern in smoke, whether from prescribed fires or wildland fires. Most of the particulate matter in smoke is PM_{2.5}, and NAAQS developed in 1997 are only now being implemented. The EPA policies that regulate particulate matter treat smoke from prescribed fire differently than wildland fire smoke, as explained in the next section.

Nonattainment designation. An area that IDEQ finds to be in violation of a NAAQS may be designated as a nonattainment area by the EPA. Nonattainment status has numerous implications for an area, including increased controls and limitations on the sources and amounts of emissions allowed. The state of Idaho currently has responsibility for three nonattainment areas—Sandpoint (Bonner Co.), Pinehurst (Shoshone Co.), and the Portneuf Valley (Bannock and Power Cos.). In addition, a federal nonattainment area administered by the EPA is located in southeastern Idaho on tribal lands. Nonattainment areas can be reclassified as maintenance areas once they have met the NAAQS and complete the appropriate planning requirements approved by the EPA.

The EPA does not count violations of the particulate matter NAAQS that are caused by natural events toward nonattainment designation if a state can document that a violation was caused by a natural event and if the state then prepares a Natural Events Action Plan (NEAP) to address human health concerns during future events. Wildland fires are considered natural events, but prescribed fires are not.

Particulate matter NAAQS violations caused by prescribed fires are addressed through the EPA's *Interim Air Quality Policy on Wildland and Prescribed Fires*. Under this policy, the EPA exercises its discretion not to designate a nonattainment area if the evidence is convincing that prescribed fires caused or significantly contributed to violations of the particulate matter NAAQS, and provided that the state develops and implements a smoke management program (SMP). An SMP works toward protecting public health and welfare by mitigating the impacts of air pollutant emissions on air quality and visibility.

Idaho policies: NEAP, SMP, etc. Idaho has both a NEAP and an SMP. Idaho's statewide NEAP was prepared in 2002, following violation of the PM₁₀ NAAQS in Salmon, Idaho, during wildland fire events in 2000.

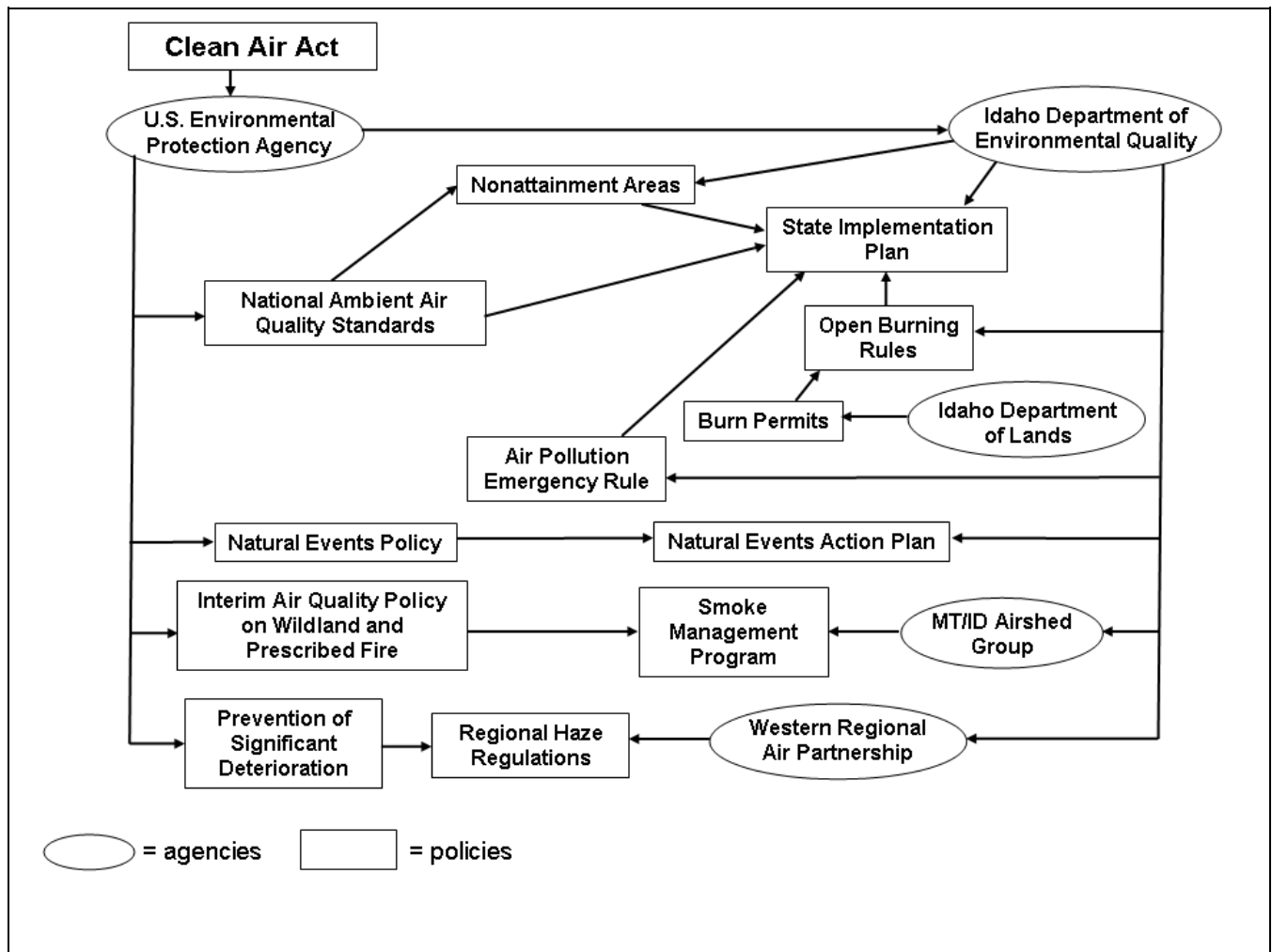


Figure 1. Policies and agencies regulating smoke emissions from wildland and prescribed fires in Idaho.

Idaho’s SMP was created and is administered jointly with the state of Montana by the Montana/Idaho Airshed Group. The group is comprised of member organizations that conduct a large amount of prescribed burning and regulatory and health agencies that regulate this burning in the states of Idaho and Montana. The intent of the Montana/Idaho Smoke Management Program is to minimize or prevent smoke impacts while using fire to accomplish land management objectives. The SMP identifies the responsibilities of Montana and Idaho air regulatory agencies, federal, state, tribal, and private land managers as well as provides accurate and reliable guidance to the individuals conducting prescribed fires. In Idaho, land manager participation in the SMP is entirely voluntary.

Other Idaho policies that address air quality and prescribed burning include IDEQ’s Air Pollution Emergency Rule that regulates activities when air pollution levels are high enough to cause a health emergency and IDEQ’s opening burning rule that regulates the types of materials that can be burned in the open. The Idaho Department of Lands (IDL) is

responsible for the control and management of fire on private forest lands in Idaho and requires permits for all open burning during the fire season (May 10 to October 20). IDL requires that burning be conducted in accordance with IDEQ’s open burning rule.

Regional partnership (WRAP). Smoke from forest fires contributes to regional haze, and the Clean Air Act has provisions that address it. Regional haze is visibility impairment produced by a multitude of sources and activities that emit particulate matter and are located across a broad geographic area. Because regional haze is a multi-state issue, the EPA’s regional haze regulations encourage states, land managers, and other stakeholders to work together to develop control programs through regional planning organizations that can coordinate development of strategies across a multi-state region. In the western U.S., the Western Regional Air Partnership (WRAP), sponsored through the Western Governors’ Association and the National Tribal Environmental Council, is coordinating regional

planning and technical assessments for implementing the regional haze regulations. Idaho is a member of WRAP.

Reducing Smoke's Impacts. There are two general approaches to managing the effects of forest fire smoke on air quality: [1] use techniques that reduce the emissions produced for a given area, and [2] redistribute the emissions through meteorological scheduling and by cooperating with other burners so that numerous fires are not burning in the same airshed at the same time.

All components of smoke from forest fires, with the exception of carbon dioxide and water, are generated by the incomplete combustion of biomass fuels. Many factors influence the amount of emissions a fire produces, including fuel abundance, fuel type, fuel size, fuel chemistry, fuel moisture, fuel temperature, fire ignition pattern, fire temperature, fire behavior, and fire duration. Many of these influences can be managed to a greater degree with prescribed fire than wildland fire, but that does not guarantee that emissions from a prescribed fire will be less than they might be during a wildland fire in the future. Emissions control may be only one of many objectives that a prescribed fire is designed to achieve, and emissions control may not be compatible with other objectives designed to alter vegetation structure.

The techniques for reducing emissions from prescribed fires can be categorized by how they work: reduce the area burned, reduce fuel load, reduce fuel production, reduce fuel consumed, schedule burning before new fuels appear, and increase combustion efficiency. Many of the techniques also may be useful for reducing emissions from wildland fires because they reduce wildland fire occurrence, extent, or intensity. Emissions are ultimately limited by the amount of fuel that burns, and techniques that directly reduce the amount of fuel that is available to burn are very effective.

Emission reduction techniques can be used independently or in combination on any given burn. Any one of the techniques may or may not be applicable in a given situation depending upon specifics of the fire's objectives, its location, time and cost constraints, weather and fuel conditions, and public and firefighter safety considerations. No two burns are the same in terms of pollutant

emissions, smoke impacts, fuel consumption, or other parameters.

Emissions can be spatially and temporally redistributed by burning during periods when atmospheric dispersion is good, burning when prevailing winds will transport smoke away from sensitive areas, burning smaller units, and burning more frequently. Managers also can coordinate ignitions of prescribed fires across an airshed so that total emissions in the airshed are controlled.

Conclusions. Can prescribed fire reduce subsequent wildland fire emissions? We reply to the question in two dimensions: one related to physical science and the other to policy. From the physical standpoint, our reply is yes, probably. The physical factors that control smoke production during a fire can be managed, but the degree of emissions reduction depends on the emphasis managers place on emissions control as an objective for implementing prescribed fire. A manager can choose to ignite a prescribed fire under conditions that reduce emissions. A wildland fire is not so selective about conditions—it burns whenever and wherever an ignition source meets fuel.

From the policy dimension, our reply is: yes. Although the Clean Air Act and other air quality laws and regulations do not directly address the trade-offs between increased smoke from prescribed fires now and potentially greater amounts of smoke from unplanned wildland fires in the future, air quality policies treat prescribed fire smoke and wildland fire smoke differently. The EPA's natural events policy and the *Interim Air Quality Policy on Wildland and Prescribed Fires* make a distinction in how particulate matter air pollution from prescribed fires and wildland fires are regulated. Both policies are lenient with violations of particulate matter NAAQS due to forest fire smoke, whether from wildland fires or prescribed fires, provided that states have approved plans and programs for smoke management in place (i.e., NEAP and SMP).

Prescribed fires can be managed to reduce the amount of smoke produced and distribute it in ways that impact people less than wildland fires do. A question remains: is the public willing to accept increased amounts of smoke now to avoid larger amounts of smoke in the future? The answer to that question is unclear.

Chapter 1. Introduction

The forests of Idaho evolved with fire. Fires, whether ignited by lightning or humans, were prevalent in Idaho's forests until the 20th century. The ecological conditions of Idaho's forests, including tree species composition and stand structure, were shaped by fire (Arno 2000, Graham et al. 2004, Jones & Stokes 2004).

Efforts to suppress almost all forest fires began with policies put in place after the Great Fires of 1910 that burned three million acres of northern Idaho and western Montana, killing 85 people (Pyne 2001). By the middle of the 20th century suppression efforts were largely successful. The acreage of forests that burned each year in Idaho and across the western United States was reduced considerably for most of the second half of the 20th century (Huff et al. 1995, Pyne 1997, USDI et al. 2001).

The situation has changed. Forest fires recently have become more frequent, more intense, and burn more acreage. A number of factors have contributed to these increases including changes in forest species composition and structure that resulted from successful fire suppression, historic timber harvesting patterns that favored some, usually shade tolerant, species over others, outbreaks of insects and diseases that resulted in tree mortality, and variations in climate (Arno and Allison-Bunnell 2002, Graham et al. 2004, Hessberg et al. 2000, Rogers et al. 2001).

Throughout the West there are large areas where current forest vegetation conditions and forest fire frequency and intensity are outside their historic ranges of variability (Graham et al. 2004, Hardy et al. 2001a, Hessberg et al. 2000, Ottmar and Sandberg 2001). This creates concern about the long-term outlook for such forests. Many forest ecologists and resource managers agree that more ecologically sustainable conditions could be attained by reintroducing fire into the forest under controlled conditions. Returning fire to the forest under controlled conditions may reduce the long-term risks associated with uncontrolled burning (Hessburg et al. 2000).

In today's terminology, fires are classified as either "prescribed fires" or "wildland fires." Prescribed fires are planned and intentionally set under controlled conditions to obtain specific management objectives. Wildland fires are all other nonstructural fires on wildlands, including forests (USFS 2004a). Wildlands are, by definition, undeveloped areas where structures, if any, are widely scattered; roads, other transportation facilities, and utility lines may be present (Firewise

2004). In official fire terminology, the commonly-used term "wildfire" means an "unwanted wildland fire" (Firewise 1998). In addition, federal land managers have a "wildland fire use" policy that allows some wildland fires to be used to achieve specific management objectives (USFS 2004e). Our report also uses the term "forest fire" to refer to all nonstructural fires in a forested environment.

Smoke emissions are a short-term effect of forest fires, occurring whether a fire is ignited under controlled or uncontrolled conditions. Smoke is made up of small particles, gases, and water vapor (Ward et al. 1994, Core and Peterson 2001). Smoke can have adverse effects on human health, affect visibility, and otherwise be a nuisance to humans (Core and Peterson 2001, Hardy et al. 2001b, Ottmar and Sandberg 2001).

Smoke and other air pollutants are regulated by a web of interrelated federal and state laws and regulations (see Figure 1 in Executive Summary). The federal Clean Air Act is the foundation for most air quality policies nationwide (Peterson 2001, Sandberg et al. 2002). It is administered by the U.S. Environmental Protection Agency (EPA) and, in Idaho, the Idaho Department of Environmental Quality (IDEQ). Laws and policies about smoke and other air pollutants reflect society's attitudes about air quality (Huff et al. 1995, Riebau and Fox 2001). During earlier periods of history, smoke was much more prevalent in the air of the western United States (Pyne 1982). Today's laws and social attitudes have restricted the amount of smoke in the air that is acceptable.

Many forest managers agree that smoke from prescribed fire under controlled conditions will have less adverse effects on air quality than allowing wildland fires to burn forests under uncontrolled conditions following lightning or human-caused ignition (Hessburg et al. 2000, Huff et al. 1995, Neuenschwander and Sampson 2000). Prescribed fire takes place under managed conditions, including the area burned, the amount of fuel burned, the moisture content in the fuels, the temperatures at which fuels burn, and the time at which the fire takes place. These factors also control the amount of smoke emitted and to some degree its effects on humans and our habitations. Unplanned fires can result in smoke emissions that are larger, occur at worse times for dispersal, and have greater impacts on areas of human habitation than prescribed fires (Huff et al. 1995).

A policy question arises. In a few words: Do clean air policies inhibit prescribed burning? In longer form: Do the laws and regulations that protect air quality allow for increased smoke from

prescribed fires in the short-term in order to prevent worse air quality from unplanned wildland fires in the future? We reply to this question by examining current federal and state policies that address the effects of smoke on air quality. This report also analyzes alternatives that may reduce the impacts of prescribed fire smoke on air quality.

The report replies to four specific Focus Questions:

1. What requirements of the federal Clean Air Act affect the use of prescribed fires for resource benefits?
2. How does current policy deal with smoke from prescribed fire in contrast to smoke from wildland fire?
3. What are the features of air quality implementation programs at the state and regional levels that affect forest landowners and forest resource managers?
4. What are the alternatives for reducing smoke, either from wildland fire or prescribed fire, and the potential benefits and detrimental effects of each alternative?

Focus Questions 1 and 2 are about federal policy, and because their answers are intertwined, we address both in Chapter 2 of this report. Many of the requirements of the federal Clean Air Act are actually implemented by the states, so in Chapter 3 we reply to Focus Question 3 about how the state of Idaho implements its air quality responsibilities. In Chapter 4 we address Focus Question 4, explaining how forest fires produce smoke, the various ways smoke from forest fires can be reduced, and findings from research designed to help reduce smoke's impacts on areas of human settlement. We present our conclusions in Chapter 5, including our reply to the short- and long-term trade-off question posed above.

We intentionally have not addressed issues regarding agricultural field burning in this report. Although both forest fires and agricultural field burning produce smoke emissions in Idaho, the specific air quality policies that cover agricultural field burning are different from those for wildland and prescribed forest fires and are beyond the scope of this report.

Chapter 2. The Federal Clean Air Act's Treatment of Smoke from Wildland and Prescribed Fires

Smoke and other airborne emissions from wildland and prescribed fires are regulated by a complex web of interrelated federal and state laws and regulations. The federal Clean Air Act is the foundation for almost all air quality regulation nationwide and is designed to protect humans against the adverse health and welfare effects of air pollution (Peterson 2001, Sandberg et al. 2002).

This chapter provides an overview of the federal Clean Air Act as it relates to emissions from wildland and prescribed fires. A considerable number of acronyms are used to describe features of implementation programs (see Table 2-1). Chapter 3 provides details about how Idaho implements provisions of the Act that are the responsibilities of the states.

2.1. Federal Clean Air Act

The federal government first became involved in air quality regulation with the Air Pollution Control Act of 1955 (P.L. 84-159). In 1963, the law was revamped and called the Clean Air Act (P.L. 88-206). It has been amended numerous times, with major revisions in 1970 (P.L. 91-604) and 1990 (P.L. 101-549) (Fleming and Knorr 2004). The U.S. Environmental Protection Agency (EPA) is the federal agency charged with implementing the Clean Air Act. The Act's purpose is "to protect and enhance the quality of the Nation's air resources so

as to promote the public health and welfare" with a goal of encouraging and promoting federal, state, and local governmental actions for pollution prevention (42 U.S. Code § 7401).

2.1.1. State Implementation Plans. Although the Clean Air Act is a federal law, the states are responsible for much of its implementation. The Act recognizes that states should have the lead in carrying out its provisions, because appropriate and effective design of pollution control programs requires an understanding of local industries, geography, transportation, meteorology, urban and industrial development patterns, and priorities (Peterson 2001, Sandberg et al. 2002).

States develop State Implementation Plans (SIPs) that define and describe customized programs that the state will implement to meet the requirements of the Clean Air Act. Individual states can require more stringent pollution standards, but cannot weaken pollution goals set by the EPA. The EPA must approve each SIP, and if a proposed or active SIP is deemed inadequate or unacceptable, the EPA can take over enforcing all or parts of the Clean Air Act requirements for that state through implementation of a Federal Implementation Plan.

The state agency in Idaho that is responsible for implementing the Clean Air Act provisions is the Idaho Department of Environmental Quality (IDEQ). IDEQ is responsible for preparing the state's SIP. Idaho's SIP has been revised substantially over the last few years, with the most recent revisions approved by the EPA in January

Table 2-1. Acronyms used to described features of Clean Air Act implementation programs.

EPA	U.S. Environmental Protection Agency
HAP	Hazardous air pollutant
IDEQ	Idaho Department of Environmental Quality
NAAQS	National Ambient Air Quality Standards
NEAP	Natural Events Action Plan
PM ₁₀	Particulate matter 10 microns or less in diameter
PM _{2.5}	Particulate matter 2.5 microns or less in diameter
PSD	Prevention of significant deterioration
SIP	State Implementation Plan
SMP	Smoke management program
WRAP	Western Regional Air Partnership

2003 (68 Fed. Reg. 2217). The Idaho SIP is examined in more detail in Chapter 3.

2.1.2. National Ambient Air Quality Standards. The EPA sets limits on how much pollution can be in the air through the National Ambient Air Quality Standards (NAAQS). The purpose of NAAQS is to establish quantitative levels of pollutants above which detrimental effects to public health or welfare may result. States are required through their SIPs to define programs for implementation, maintenance, and enforcement of NAAQS within their boundaries.

NAAQS have been established for six air pollutants: particulate matter (PM₁₀ and PM_{2.5}), sulfur dioxide (SO₂), nitrogen dioxide (NO₂), ozone, carbon monoxide (CO) and lead (Pb). Primary and secondary standards are set for each pollutant. Primary standards are designed to protect public health, including the health of sensitive populations such as asthmatics, children, and the elderly. Secondary standards are designed to protect public welfare, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings.

Particulate matter (PM₁₀ and PM_{2.5}) is the primary pollutant of concern from forest fire smoke. PM₁₀ is particulate matter less than 10 microns in diameter, and PM_{2.5} is less than 2.5 microns in diameter. By comparison, the average human hair is about 70 microns in diameter. NAAQS for PM_{2.5} and PM₁₀ are established for two different time periods: an annual average and a 24-hour average (Table 2-2). The primary and secondary NAAQS for PM_{2.5} and PM₁₀ are identical (62 Fed. Reg. 38651). NAAQS for PM_{2.5} have been controversial (Sidebar 2-1).

Studies indicate that 70% of the smoke particles emitted by wildland fires are PM_{2.5} (Ottmar 2001).

About 20% is particulate matter between 2.5 and 10 microns, and the rest (10%) is larger than 10 microns. The most recent human health studies on the effects of particulate matter indicate that it is fine particles, especially PM_{2.5}, that are largely responsible for health effects including mortality, exacerbation of chronic disease, and increased hospital admissions (EPA 2004e, Peterson 2001, Sandberg et al. 2002).

2.1.3. Nonattainment Areas. An area that is found to be in violation of a primary NAAQS is labeled a nonattainment area. Nonattainment status has numerous implications for an area and the state agency that implements the Clean Air Act's provisions. With each nonattainment designation the EPA establishes a date by which an area must meet the NAAQS. The state must then create a plan for attaining the standard by that date. The plan must include:

- provisions for implementing "all reasonably available control measures as expeditiously as practical";
- provisions for identifying the sources of the pollutant and quantifying emissions by each source;
- permitting systems for new or modified major stationary sources of the pollutant; and
- enforceable emissions limitations (42 U.S. Code § 7502).

Nonattainment areas can be reclassified as maintenance areas once they have met the NAAQS and the state has completed the appropriate planning requirements approved by the EPA. All other areas are classified as attainment areas or are unclassified due to lack of monitoring.

Table 2-2. National Ambient Air Quality Standards (NAAQS) for particulate matter.

	Averaging Time	Primary Standard	Secondary Standard
Respirable Particulate Matter (10 microns or less) (PM ₁₀)	24-hour	150 µg/m ³ *	150 µg/m ³
	Annual	50 µg/m ³	50 µg/m ³
Respirable Particulate Matter (2.5 microns or less) (PM _{2.5})	24-hr	65 µg/m ³	65 µg/m ³
	Annual	15 µg/m ³	15 µg/m ³

* µg/m³ = micrograms per cubic meter

Source: 40 CFR 50.6-50.7

Sidebar 2-1. Legal Challenges to the PM_{2.5} NAAQS.

In July 1997, the EPA issued revised NAAQS for particulate matter, including for the first time PM_{2.5} standards separate from the PM₁₀ standards (62 Fed. Reg. 38652). At the same time, the EPA also revised the NAAQS for ozone (62 Fed. Reg. 38856). The new regulations prompted the filing of a series of lawsuits by industrial organizations and several states. The cases were consolidated into *American Trucking Association v. EPA* (175 F.3d 1027).

Among the petitioners' claims were:

- the section of the Clean Air Act that authorizes the EPA to develop the NAAQS was an unconstitutional delegation of legislative power by Congress;
- the EPA should have considered implementation costs when setting NAAQS;
- the EPA had no authority to revise the ozone standards, and its implementation policy was illegal;
- there was no scientific basis for regulating coarse particulate matter (2.5 to 10 microns); and
- retaining the PM₁₀ standard while also establishing the PM_{2.5} standard was unsupported by evidence and therefore an arbitrary and capricious action.

In 1999, the U.S. Court of Appeals for the District of Columbia ruled that the portion of the Clean Air Act that authorizes the EPA to set NAAQS was unconstitutional (175 F.3d 1027); however, that decision was reversed by the U.S. Supreme Court in 2001 (531 U.S. 457). The appeals court also ruled, and the Supreme Court upheld, that the EPA may not consider implementation costs when setting NAAQS. With regard to the ozone standards, the courts ruled that the EPA had the authority to revise the standards; however, the courts agreed that the implementation policy was unlawful.

The appeals court also found that there was an adequate scientific basis for regulating coarse particulate matter; however, the 1997 PM₁₀ indicator that the EPA had chosen for coarse particle pollution was arbitrary and therefore illegal (283 F.3d 355). However, the court found that the PM_{2.5} and existing (1987) PM₁₀ NAAQS were lawful. The EPA has begun to implement the 1997 PM_{2.5} NAAQS, but is also reassessing both the PM₁₀ and PM_{2.5} standards (68 Fed. Reg. 36985; EPA 2004e).

Idaho currently has responsibility for three nonattainment areas: the Sandpoint area of Bonner County, the Pinehurst area of Shoshone County, and the Portneuf Valley area of Bannock and Power Counties (EPA 2004b, IDEQ 2004). In addition, the EPA has responsibility for the federal Fort Hall Reservation nonattainment area of Bannock and Power Counties (63 Fed. Reg. 59722). Each of the four areas is classified as a nonattainment area because of violations of the PM₁₀ NAAQS. The Northern Ada County PM₁₀ nonattainment area was reclassified as a maintenance area in October 2003 (68 Fed. Reg. 61106). Smoke from prescribed or wildland fires was not identified as a cause of PM₁₀ nonattainment for any of Idaho's nonattainment areas.

The EPA expects to designate nonattainment areas for PM_{2.5} by the end of 2004 (EPA 2004c). States were required to provide the EPA with a list of potential nonattainment areas for PM_{2.5} in February 2004. Idaho did not submit any potential nonattainment areas for PM_{2.5} (EPA 2004d).

2.1.4. Natural Events Policy. Exceedances of the PM₁₀ NAAQS that are caused by natural events are not counted toward nonattainment designation if a state can document that an exceedance was caused by a natural event and if the state then prepares a

Natural Events Action Plan (NEAP) to address human health concerns during future events (Nichols 1996). Natural events are defined by this policy as wildfire, volcanic, seismic, and high wind events. The EPA has indicated that PM_{2.5} exceedances caused by natural events will fall under the same policy (Wegman 2004).

A NEAP is developed by the state air pollution control agency (IDEQ in Idaho) in conjunction with the stakeholders affected by the plan. When developing a wildland fire NEAP, a state must gather input from federal, state, and private land managers in areas vulnerable to fire. Agencies responsible for suppressing fires, local health departments, and citizens in the affected area also can be involved in developing the plan. NEAPs include documented agreements among stakeholders regarding planned actions and the parties responsible for carrying out those actions. Idaho's statewide Natural Events Action Plan is reviewed in Chapter 3.

A wildland fire NEAP includes commitments by the state and stakeholders to:

- a. Establish public notification and education programs.
- b. Minimize public exposure to high concentrations of PM₁₀ due to future natural events, including:
 - identifying the people most at risk,

- notifying the at-risk public that an event is active or imminent,
 - recommending actions to be taken by the public to minimize their pollutant exposure, and
 - suggesting precautions to take if exposure cannot be avoided.
- c. Abate or minimize controllable sources of PM₁₀ including the following:
- prohibition of other burning during pollution episodes caused by wildland fire,
 - proactive efforts to minimize fuel loadings in areas vulnerable to fire, and
 - planning for prevention of NAAQS exceedances in fire management plans.
- d. Identify, study, and implement practical mitigating measures as necessary.
- e. Periodic reevaluation of the NEAP (Nichols 1996).

Prescribed fires are not considered natural events, even if they are planned to mimic the natural role of fire in the ecosystem. Instead, the *Interim Air Quality Policy on Wildland and Prescribed Fires* (EPA 1998) applies (see next section, 2.1.5). That policy states that the EPA will exercise its discretion not to designate an area as a nonattainment area if the evidence is convincing that [1] fires managed for resource benefits caused or significantly contributed to violations of the daily or annual PM_{2.5} or PM₁₀ standards, and [2] the state has a formal smoke management program (see section 2.1.6).

Preparation of a NEAP provides the opportunity for land managers to formally document, in cooperation with state air quality agencies, that it is appropriate to consider prescribed fire a prevention, control, and mitigation measure for wildland fire. Prescribed fire can be used to minimize fuel loadings in areas vulnerable to fire so that future wildland fires can be contained in a smaller area, thereby producing fewer emissions. The NEAP can therefore lead to a greater understanding by state air quality agencies of the potential air quality benefits from some types of prescribed fire in certain ecosystems (Peterson 2001).

2.1.5. Interim Air Quality Policy on Wildland and Prescribed Fires. Recent policy debate has focused on what types of fires should be considered “natural.” In the past, emissions from prescribed fire were considered human-caused, and wildland fires were considered natural sources of emissions. The current debate has resulted from the paradox that not all wildland fires are vigorously suppressed and that some prescribed burning is done to maintain healthy

wildland ecosystems where fire has previously been excluded (Sandberg et al. 2002).

In 1998, the EPA issued a national policy to address how best to achieve national clean air goals while improving the quality of wildland ecosystems through the increased use of fire. The *Interim Air Quality Policy on Wildland and Prescribed Fires* (EPA 1998) was developed through a partnership effort involving the EPA, the U.S. Departments of Agriculture, Defense, and the Interior, state foresters, state and tribal air quality regulators, and others. The group that developed the policy relied on the assumption that properly managed prescribed fires can improve the health of wildland ecosystems and reduce the health and safety risks associated with wildland fire, while meeting clean air and public health goals through careful planning and cooperation among land managers, air quality regulators, and local communities (Sandberg et al. 2002).

The interim policy’s goals are: [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 (EPA 1998). The policy urges state air quality managers to collaborate with wildland owners and managers to mitigate the air quality impacts that could be caused by the increased use of fires that are managed to achieve resource benefits. The EPA especially urges development and implementation of a smoke management program (SMP) when conditions indicate that fires will adversely impact the public (see next section, 2.1.6). In exchange for a state proactively implementing its SMP, the EPA will exercise its discretion not to designate a nonattainment area if the evidence is convincing that fires managed for resource benefits caused or significantly contributed to violations of the particulate matter NAAQS. Instead, the EPA will ask the state to review the adequacy of its SMP in collaboration with wildland owners and managers and make appropriate improvements to mitigate future air quality impacts (EPA 1998). The interim policy applies to both PM₁₀ and PM_{2.5} violations. In practice, documenting that the source of a violation was caused by fire managed for resource benefits can be difficult, particularly if several sources of smoke existed or the annual particulate matter NAAQS were violated (D. Riley, review comments).

The interim policy is directed towards all forest lands, not just those in public ownership. The policy states that it “is not intended to limit opportunities by private wildland owners/managers to use fire so

that burning can be increased on publicly owned wildlands” (EPA 1998).

Although the policy has been titled “interim” since 1998, the EPA has not finalized the policy through administrative rules in the Code of Federal Regulations. We were not able to find solid evidence of EPA’s plans or schedule for making the policy permanent.

2.1.6. Smoke Management Programs. States must adopt a basic smoke management program (SMP) in order to qualify for special consideration in designating nonattainment areas caused by prescribed fire smoke under the *Interim Air Quality Policy on Wildland and Prescribed Fires* (EPA 1998). The purposes of an SMP are [1] to mitigate the nuisance and public safety hazards posed by smoke intrusions into populated areas; [2] to prevent deterioration of air quality and NAAQS violations; and [3] to address visibility impacts in Class I federal areas (see sections 2.1.7 and 2.1.8). An SMP establishes a basic framework of procedures and requirements for managing smoke from fires managed for resource benefits. An SMP is typically developed by a state with the cooperation and participation of owners and managers of wildlands (EPA 1998).

Although an SMP does not have to be incorporated in the State Implementation Plan (SIP), states must certify to EPA that a basic SMP is being implemented. The EPA prescribes the basic components that must be in an SMP in order to be certifiable, but considerable latitude is granted as to what elements can be within each component (EPA 1998). An SMP should include the following basic components:

- A process for authorizing and granting approval of prescribed burns;
- Identification of ways to minimize air pollutant emissions from prescribed fire activities, including promotion of alternatives to burning and use of emission reduction techniques;
- If burn plans are required, they should include:
 - actions to minimize fire emissions,
 - smoke dispersion evaluation,
 - public notification and exposure reduction procedures, and
 - air quality monitoring;
- A plan for public education and awareness;
- Procedures for surveillance and enforcement of SMP compliance; and
- A plan for program evaluation and periodic review (EPA 1998).

Optional SMP components include special protection zones and performance standards (EPA 1998).

Idaho’s smoke management program is reviewed in Chapter 3 of this report.

2.1.7. Prevention of Significant Deterioration:

Three Air Quality Classifications. Another provision of the Clean Air Act with applicability to prescribed and wildland fire activities is prevention of significant deterioration (PSD) (42 U.S. Code § 7470 et seq.). The goal of PSD is to prevent areas that are currently cleaner than allowed by the NAAQS from being polluted up to the maximum ceiling established by the NAAQS.

Three air quality classes are established by the Clean Air Act PSD provisions: Class I, Class II, and Class III. Class I areas are subject to the tightest restrictions on how much additional pollution can be added to the air. Class I areas include U.S. Forest Service wildernesses and national memorial parks over 5,000 acres, national parks exceeding 6,000 acres, and international parks, all of which must have been in existence as of August 7, 1977, plus later expansions to these areas. These original Class I areas are declared “mandatory” and can never be redesignated to another air quality classification. In addition, a few Indian tribes have redesignated their lands to Class I. Redesignated Class I areas are not mandatory Class I areas so are not automatically protected by all the same rules as defined by the Clean Air Act unless a state or tribe chooses to do so. Since no areas have ever been designated Class III, all other lands are Class II, including everything from non-Class I wildlands to urban areas.

Class I areas in Idaho include the Sawtooth Wilderness Area and Craters of the Moon National Monument. In addition, Idaho shares three Class I areas with neighboring states: the Selway-Bitterroot Wilderness with Montana, Hell’s Canyon National Recreation Area with Oregon, and Yellowstone National Park with Montana and Wyoming (IDEQ 2002).

States use the permitting requirements of the PSD program to manage and limit air pollution increases over a baseline concentration. A PSD baseline is the pollutant concentration at a point in time when the first PSD permit was issued for the airshed. New or modified major air pollution sources must apply for a PSD permit prior to construction and test their proposed emissions against allowable PSD increments.

Historically, the EPA has regarded smoke from wildland fires as temporary and therefore not subject to issuance of a PSD permit, but whether or not

wildland fire smoke should be considered when calculating PSD increment consumption or PSD baseline was not defined. The EPA recently reaffirmed that states could exclude managed fire emissions from increment analyses, provided the exclusion does not result in permanent or long-term air quality deterioration (EPA 1998). States are also expected to consider the extent to which a particular type of burning activity is truly temporary, as opposed to an activity that can be expected to occur in a particular area with some regularity over a period of time. Oregon is the only state that has thus far chosen to include prescribed fire emissions in PSD increment and baseline calculations (Peterson 2001, Sandberg et al. 2002).

2.1.8. Visibility. The 1977 amendments to the Clean Air Act include a national goal of “the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution” (42 U.S. Code § 7491). The visibility protection program is designed to address visibility impairment that is attributable to a specific source or a small group of sources (64 Fed. Reg. 35715). States are required to revise their SIPs to assure “reasonable progress” toward the national visibility goal (64 Fed. Reg. 35717).

Atmospheric visibility is influenced by scattering and absorption of light by particles and gases. Particles and gases in the air can obscure the clarity, color, texture, and form of what people see. The fine particles most responsible for visibility impairment are sulfates, nitrates, organic compounds, elemental carbon (or soot), and soil dust. Wildland fire smoke is primarily made up of elemental carbon, organic carbon, and particulate matter (Peterson 2001).

Naturally occurring visual range in the western U.S. is estimated between 110-115 miles. Currently, visual range in the western U.S. averages about 60 to 90 miles (64 Fed. Reg. 35715, Core 2001, Peterson 2001, Sandberg et al. 2002).

2.1.9. Regional Haze. Regional haze is visibility impairment produced by a multitude of sources and activities that emit fine particles and their precursors and are located across a broad geographic area. This contrasts with visibility impairment that can be traced largely to a single, large pollution source (see previous section, 2.1.8). For several years, the only regulations for visibility protection addressed impairment that is reasonably attributable to a permanent, large emission source or small group of large sources. In 1999, the EPA issued regional haze

regulations to manage and mitigate visibility impairment from the multitude of diverse regional haze sources (64 Fed. Reg. 35713; 40 CFR Part 51). The 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 fire is one of the sources of regional haze covered by the regional haze regulations.

The regional haze regulations did not define visibility targets but instead gave states flexibility in determining “reasonable progress” goals for Class I areas. States are required to conduct analyses to ensure that they consider the possibility of setting an ambitious reasonable progress goal, one that is aimed at reaching natural background conditions in 60 years. The rule requires states to establish goals for each affected Class I area to [1] improve visibility on the haziest 20% of days, and [2] ensure no degradation occurs on the clearest 20% of days over the period of each implementation plan.

Regional haze is, by definition, from widespread, diverse sources. Because regional haze is a multi-state issue, EPA’s regional haze regulations encourage states, land managers, and other stakeholders to work together to develop control programs through regional planning organizations that can coordinate development of strategies across a multi-state region. This means that groups of states are addressing groups of Class I areas through established organizations.

In the western U.S., the Western Regional Air Partnership (WRAP), sponsored through the Western Governors’ Association and the National Tribal Environmental Council, is coordinating regional planning and technical assessments for implementing the regional haze regulations. The WRAP was the first of five regional planning organizations to be established and has been active in many technical and policy developments. Idaho participates in the WRAP (see section 3.8). Other regional planning organizations have begun assessments of fire and air quality in their regions.

2.1.10. Hazardous Air Pollutants. Hazardous air pollutants (HAPs) are identified in Title III of the Clean Air Act Amendments of 1990 (P.L. 101-549) as 188 different pollutants “which present, or may present, through inhalation or other routes of exposure, a threat of adverse human health or environmental effects whether through ambient concentrations, bioaccumulation, deposition, or other routes.” The listed HAPs are substances which are known or suspected to be carcinogenic,

mutagenic, teratogenic, neurotoxic, or which cause reproductive dysfunction. The six pollutants that are regulated through the NAAQS are excluded from the list of HAPs.

Although the principal air pollutant of concern in forest fire smoke is particulate matter, HAPs are among the hundreds of other compounds emitted by wildland fires. The most prevalent HAPs in wildland fire smoke are acrolein, formaldehyde, anthracene, and benzene (Core and Peterson 2001). HAPs in wildland fire smoke are of concern to wildland fire fighters and others directly involved in burning projects (Ottmar and Reinhardt 2001), but concentrations are low enough that their effects are not widespread. Wildland fire sources of HAPs are not regulated by the EPA.

2.1.11. Federal Land Management Agency Actions.

The 1990 Clean Air Act Amendments require that actions planned by federal agencies conform to SIPs. This “general conformity rule” prohibits federal agencies from taking any action within a nonattainment or maintenance area that [1] causes or contributes to a new violation of air quality standards, [2] increases the frequency or severity of an existing violation, or [3] delays the timely attainment of a standard as defined in the applicable SIP or area plan. The general conformity rule covers direct and indirect emissions of the six NAAQS pollutants, or their precursors, which are caused by federal agency actions, are reasonably foreseeable, and can practicably be controlled by the federal agency through its continuing program responsibility (40 CFR 93.150-160).

Chapter 3. Idaho's Clean Air Policies for Smoke from Wildland and Prescribed Fires

The federal Clean Air Act delegates much of the responsibility for implementing the law's provisions to the states. This chapter describes how Idaho implements its responsibilities under the Clean Air Act. We also describe other Idaho air quality policies for wildland and prescribed fires. In addition, some provisions of the Clean Air Act are addressed by multi-state or regional groups; Idaho's participation in those groups is also described.

3.1. Idaho's State Implementation Plan

As discussed previously (section 2.1.1), states develop State Implementation Plans (SIPs) that define and describe customized programs that they will implement to meet the requirements of the Clean Air Act. The U.S. Environmental Protection Agency (EPA) must approve the SIP that each state uses.

Idaho's SIP is an extensive, multi-volume document that is periodically updated to address changes in air pollution conditions and control programs within Idaho (M. Edwards, personal communication). Many elements of the SIP, including the chapters on administration, emissions inventory, air quality monitoring, source surveillance, and emergency episode plans, were adopted by Idaho and approved by the EPA in 1980 (EPA 2004a; 40 CFR 52.679). Nonattainment area plans are included in more recent updates. These plans are updated as new nonattainment areas are identified and control and clean-up measures are implemented.

3.2. Idaho's Natural Events Action Plan

As discussed previously (section 2.1.4), violations of the PM₁₀ NAAQS caused by natural events are not counted toward nonattainment designation under two conditions: [1] the state can document that the violation was caused by a natural event, and [2] the state also prepares a Natural Events Action Plan (NEAP) to address human health concerns during future events. In Idaho, wildland fires are considered natural events for the purposes of this policy, and Idaho has a statewide NEAP. In practice, documenting that the source of a violation was caused by a natural event can be difficult, particularly if several sources of smoke existed or the annual PM₁₀ NAAQS was violated (D. Riley, review comments).

The purpose of Idaho's NEAP is to protect public health during natural wildland fire events and fulfill the requirements of EPA's policy on natural

events. Idaho's NEAP was prepared in 2002, following violation of the PM₁₀ NAAQS in Salmon, Idaho, during wildland fire events in 2000. While the majority of smoke impacts in 2000 occurred in central Idaho, this NEAP applies statewide because smoke impacts could potentially occur anywhere in the state. As required by the EPA, the Idaho NEAP contains the following elements:

1. Public notification and education programs,
2. Minimization of public exposure,
3. Abatement or minimization of controllable sources,
4. Identification, study, and implementation of mitigation measures, and
5. Periodic evaluation (IDEQ 2002).

3.3. Idaho's Air Pollution Emergency Rule

As part of its obligations under the Clean Air Act, Idaho has an Air Pollution Emergency Rule (IDAPA 58.01.01.550-562). The rule establishes criteria for taking appropriate action when air pollution levels cause a health emergency, or are predicted to cause one. The rule is included as an abatement or minimization strategy under Idaho's NEAP (IDEQ 2002).

The rule identifies emergency stages 1 to 4, with each higher stage addressing a progressively more serious air quality event. IDEQ has rarely needed to invoke emergency stage 1, and has never invoked any of the higher stages. During an emergency stage 1, IDEQ must call for a temporary ban on new ignition of open burning. This limits the ignition of any new sources of open burning and allows existing fires to burn out. IDEQ may require, if practical or in an emergency situation, the cessation of any open burning. Extinguishing fires depends on available resources and may even further degrade air quality due to smoldering (IDEQ 2002).

3.4 Idaho's Rules for Open Burning

Idaho addresses smoke from prescribed fires through its rules for control of open burning (IDAPA 58.01.01.600). The rules are designed to protect public health and welfare from air pollutants. Cities, counties, or other governmental entities or agencies are allowed to provide equal or more stringent control of open burning within their respective jurisdictions (IDAPA 58.01.01.602).

Except when an emergency stage is declared (see section 3.3), prescribed fires are allowed provided they meet the following conditions (IDAPA 58.01.01.614):

- If a burning permit or prescribed fire permit is required by the Idaho Department of Lands (see section 3.5), the U.S. Forest

Service, or any other state or federal agency responsible for land management, the burner must meet all permit and/or plan conditions and terms which control smoke.

- If permits from these other agencies are not required, burners must meet conditions in the Montana/Idaho State Airshed Group's smoke management program (see sections 3.6 and 3.7). (However, because participation in the smoke management program is voluntary, the effect of this rule is that only members of the airshed group must abide by the smoke management program.)

3.5. Idaho Department of Lands Burn Permits

The Idaho Department of Lands (IDL) is responsible for the control and management of fire on private forest lands in Idaho (Idaho Code 38-101 et seq.). IDL requires permits for all open burning (except within incorporated city limits) during the fire season (May 10 to October 20) to ensure that burning is kept under control and prevented from spreading to other property. IDL can suspend burn permits during times of extreme fire danger (Idaho Code 38-115).

IDL burn permits specify that burning must be conducted in accordance with IDEQ's open burning rule (see section 3.4). For certain areas in north Idaho, burners must also call the IDEQ air quality hotline to learn about any burn restrictions.

Timber harvesters in Idaho must treat logging slash in order to reduce fire hazard and are required to post a bond to ensure compliance (Idaho Code 38-122; IDAPA 20.04.01.050). Burning is an acceptable method for reducing slash, but alternatives to burning such as chipping, crushing, and lopping are also acceptable (IDEQ 2002; IDAPA 20.04.02.120).

3.6. Montana/Idaho Airshed Group

The Montana/Idaho Airshed Group is comprised of member organizations that conduct a large amount of prescribed burning and regulatory and health agencies that regulate this burning in the states of Idaho and Montana. The purpose of the Airshed Group is to coordinate actions that will minimize or prevent smoke impacts while using fire to accomplish land management objectives and/or fuel hazard reduction (Montana/Idaho Airshed Group 2004).

The *Montana/Idaho Airshed Group Operating Guide* (2004) serves as the smoke management program (SMP) for Montana and Idaho (see section 2.1.6 and next section, 3.7). The guide is reviewed

annually and revised as necessary (Montana/Idaho Airshed Group 2004).

The Airshed Group is comprised of three geographic Airshed Units: Montana, North Idaho, and South Idaho. Each Airshed Unit has a Memorandum of Agreement, which describes its responsibilities under the SMP and commits its signatories to abide by the SMP and the operating guide. Current Idaho members of the Montana/Idaho Airshed Group are identified in Table 3-1.

For operational purposes, the three Airshed Units are divided into 28 geographically defined airsheds that may be further subdivided if necessary. Each airshed has an Airshed Coordinator, who acts as a point of contact for the airshed. Within each airshed are various field offices of the member organizations that form a local airshed committee. Participation on the committee by non-member organizations and county officials is encouraged. The field offices are the level where final responsibility for burning lies. By virtue of signing the Memorandum of Agreement, each signatory receives full membership in their respective Airshed Unit and therefore in the Airshed Group (Montana/Idaho Airshed Group 2004).

The Monitoring Unit for the Montana/Idaho Airshed Group is located in Missoula, Montana and is the administrative unit that coordinates prescribed burning activities of the three Airshed Units. The Monitoring Unit operates on a full-time basis only during the spring and fall burning seasons. Airshed Group members abide by the operating procedures of the Monitoring Unit in order to prevent or reduce smoke impacts (Montana/Idaho Airshed Group 2004).

3.7. Montana/Idaho Smoke Management Program

As discussed previously (section 2.1.5), the EPA's *Interim Air Quality Policy on Wildland and Prescribed Fires* (EPA 1998) urges state air quality managers to collaborate with owners and managers of wildlands to mitigate the air quality impacts that could be caused by the use of prescribed fires. The EPA urges development and implementation of smoke management programs (SMPs) when conditions indicate that fires will adversely impact the public (see section 2.1.6). The states of Idaho and Montana have joined together to create and implement a joint SMP.

The intent of the Montana/Idaho Smoke Management Program is to minimize or prevent smoke impacts while using fire to accomplish land management objectives (Montana/Idaho Airshed Group 2004). The SMP identifies the responsibilities

Table 3-1. Current Idaho members of the Montana/Idaho Airshed Group.

North Idaho Airshed Unit

Coeur d'Alene Tribe
 Forest Capital Partners
 Idaho Department of Environmental Quality
 Idaho Department of Lands
 Inland Empire Paper
 Potlatch Corporation
 Plum Creek Timber Company

Stimson Lumber Company
 University of Idaho
 USDA Forest Service
 U.S. Army Corp of Engineers
 U.S. Bureau of Land Management
 U.S. Fish and Wildlife Service

South Idaho Airshed Unit

Boise Cascade Corporation
 Idaho Department of Environmental Quality
 Idaho Department of Lands
 National Weather Service

USDA Forest Service
 U.S. Bureau of Land Management
 U.S. Fish and Wildlife Service

Source: Montana/Idaho Airshed Group 2004.

of Montana and Idaho air regulatory agencies, federal, state, tribal, and private land managers as well as provides accurate and reliable guidance to the individuals conducting prescribed fires (Battye et al. 1999, Montana/Idaho Airshed Group 2004).

Each land management agency or entity is encouraged to consider and evaluate alternative treatments other than fire to achieve land management objectives. If there is no feasible alternative to using fire, the land manager is to employ emission reduction techniques and be responsible for proper smoke management. This includes preparing the proper burn documentation and providing personnel training in smoke management techniques. Each land manager is supposed to adhere to the operating procedures outlined in the SMP (Montana/Idaho Airshed Group 2004).

The goals of the SMP are to:

- Minimize or prevent the accumulation of smoke in Montana and Idaho from prescribed fire to such a degree as is necessary to meet state and federal ambient air quality standards;
- Provide for the use of prescribed burning as necessary for purposes such as hazard reduction, forest/rangeland regeneration and wildlife habitat management;
- Report and coordinate burning operations on forests and rangelands in Montana and Idaho;
- Evaluate the SMP annually and revise as necessary;

- Ensure burning activities are conducted during periods of optimal smoke dispersion and air quality conditions as advised by the Monitoring Unit in Missoula; and
- Meet the requirements of EPA's interim policy on wildland and prescribed fire (Montana/Idaho Airshed Group 2004).

In Idaho, participation in the SMP is entirely voluntary. Those that wish to be a part of the program become members by signing a memorandum of agreement to abide by the program. The North Idaho Smoke Management Memorandum of Agreement went into effect in 1990. The South Idaho Smoke Management Memorandum of Agreement went into effect in 1999. Current members of the North Idaho Airshed Unit and South Idaho Airshed Unit are listed in Table 3-1.

Burners submit planned burn lists at the beginning of the calendar year and again in July of each year. Individual burns are reported the day prior to ignition. Burn information includes burn type, acres, location, and elevation. Burners report the burn date and accomplished acres (blackened) for each burn at the end of the year. Burn plans must include actions to minimize fire emissions, smoke dispersion evaluation, public notification and exposure reduction procedures, and an air quality monitoring plan (IDEQ 2002).

A meteorologist contracted by the Montana/Idaho Airshed Group provides smoke dispersion forecasts, and the Program Coordinator at the Monitoring Unit uses burn activity, weather, and air quality information to make burn go/no go recommendations (Montana/Idaho Airshed Group

2004). IDEQ reviews all burn recommendations made by the Monitoring Unit and provides advice on potential air quality impacts (Montana/Idaho Airshed Group 2004). However, the final responsibility for ignition and smoke management rests with the member burner (IDEQ 2002).

Burners must have training in smoke management techniques, which is provided by the Airshed Group. The burner must obtain burn restriction information on burn days from hotlines, the group's website, or the airshed coordinator. Burners curtail burning, if in their best judgment, smoke dispersion is not adequate even when no restrictions are in place. Conversely, if burners believe smoke dispersion conditions are favorable, but there are restrictions in place, the burner may request an exemption. Membership may be revoked for participants who do not comply with the program (IDEQ 2002).

3.8. Western Regional Air Partnership

The Western Regional Air Partnership (WRAP) is the regional organization that is implementing the regional planning process to improve visibility in all Class I areas in the western U.S. (WRAP 2003b; see sections 2.1.7 and 2.1.8). WRAP is funded by the EPA and administered through the Western Governors' Association and the National Tribal Environmental Council. WRAP provides technical and policy tools for states and tribes to implement the federal regional haze administrative rules (see section 2.1.9). WRAP includes 13 western states (Idaho is one), 10 tribal governments, and 3 federal agencies.

Most of the work of WRAP is done through committees and forums. The Fire Emissions Joint Forum (FEJF) is the primary group addressing fire effects on air quality and visibility. The FEJF is addressing the following areas for all types of fires, including wildland and prescribed fires:

- basic and enhanced smoke management programs (WRAP 2001b and 2002),
- prescribed fire program assessment,
- alternatives to burning (Jones & Stokes 2004),
- fire emission inventory and assessment,
- natural visibility conditions, and
- public education and outreach (IDEQ 2002).

WRAP committees and forums seek consensus among governmental partners and stakeholders including large and small businesses, academia, environmental groups, and other public interest representatives (IDEQ 2002; WRAP 2003b). Scientific findings and policy options are presented to policy makers and the public for discussion and

response. WRAP is committed to bringing together all those who may contribute to or be affected by poor air quality. Findings and policy options go before the WRAP Board for approval and adoption (WRAP 2003b).

One of the policies that WRAP has adopted is a policy on fire-tracking systems (WRAP 2003a). The policy identifies seven essential components of a fire tracking system that represent the minimum spatial and temporal fire activity information necessary to consistently calculate emissions and to meet the requirements of EPA's regional haze regulations. The essential components include: date of burn, burn location, area of burn, fuel type, pre-burn fuel loading, type of burn, and anthropogenic or natural classification (WRAP 2003a). WRAP also has adopted a policy for categorizing fire emissions as either anthropogenic or natural as required by the regional haze regulations (WRAP 2001a).

3.9. Western States Air Resources Council

The Western States Air Resources Council (WESTAR) does not have any legislated duties under the Clean Air Act. It is a regional organization formed to promote the exchange of information between western states. It serves as a forum to discuss western regional air quality issues of common concern and share resources for the common benefit of the member states. WESTAR was founded in 1988 by eight western state air agencies and has grown to fifteen states including Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. WESTAR's federal land management partners include, the U.S. Department of the Interior's National Park Service, Fish and Wildlife Service, and Bureau of Land Management, and the U.S. Department of Agriculture Forest Service. WESTAR is funded primarily by grants from the EPA (WESTAR 2004). Idaho's representative to WESTAR is Martin Bauer, Program Administrator, Idaho Air Quality Division, IDEQ.

The specific purposes of WESTAR are to:

- Promote the exchange of information related to the control of air pollution for use in state and federal activities as authorized by air quality statutes and regulations;
- Develop processes and procedures for consideration by western states, federal land managers and the EPA in order to meet air quality objectives and to protect the environmental resources;
- Discuss air quality issues of common concern;

- Report on the status of efforts undertaken to achieve air quality objectives;
- Establish work groups, task forces, etc., to investigate specific topics and to recommend a course of action for Council members; and
- Adopt resolutions and policy statements for implementation by Council members or for their use during the development of local, state and federal programs, regulations, and laws (WESTAR 2004).

Chapter 4. Forest Fire Smoke Reduction and Impact Control

This chapter reviews techniques that forest and fire managers can use to reduce the amount of smoke that forest fires emit, thereby reducing smoke's impacts on humans. While the techniques focus on reducing emissions from prescribed fires, the techniques also may be useful for reducing emissions from wildland fires because they intentionally reduce wildland fire occurrence, extent, or severity (Ottmar et al. 2001).

Before reviewing smoke reduction techniques, we review the physical and chemical processes of combustion and smoke production and examine potential management objectives for prescribed fire. This information provides the bases for understanding the ways in which smoke reduction techniques work and their potential effectiveness.

This chapter relies heavily on the *Smoke Management Guide for Prescribed and Wildland Fire: 2001 Edition* published by the National Wildfire Coordination Group (Hardy et al. 2001c), and particularly on the chapter of the guide that focuses on smoke management techniques (Ottmar et al. 2001). The U.S. Environmental Protection Agency also has documented emissions reduction techniques for prescribed fires (EPA 1992). The Fire Emissions Joint Forum of the Western Regional Air Partnership (see section 3.8) also has compiled a bibliography of research on emissions reduction techniques (WRAP 2003c).

Much of the information in Ottmar et al. (2001) is based on the knowledge and experience of fire practitioners from across the nation who participated in a series of workshops in 1999. The practitioners were asked to describe how they apply emission reduction techniques in the field, how frequently the methods are used, how effective they are, and what constraints limit their wider use (Ottmar et al. 2001).

There are two general approaches to managing the effects of forest fire smoke on air quality: [1] use techniques that reduce the emissions produced for a given area, and [2] redistribute the emissions through meteorological scheduling and by sharing the airshed (Ottmar et al. 2001).

4.1. How Forest Fires Produce Smoke

In order to understand the ways smoke from forest fires can be reduced, it is helpful to understand how burning and smoke production occur. Reducing smoke, or the potential for smoke, from forest fires is more complicated than simply reducing the amount of fuel that is available to burn.

In simple terms, burning is a thermal and chemical reaction whereby fuel is rapidly oxidized, producing carbon dioxide, water, and heat (Ottmar 2001). Smoke is produced as a result of incomplete burning. In reality, burning and smoke production are much more complex processes (Chandler et al. 1983, Ottmar 2001, Pyne 1984, Sandberg et al. 2002, Ward 2001).

Burning is a two stage process, first pyrolysis and then combustion (Chandler et al. 1983, Ottmar 2001, Ward 2001). Pyrolysis is a heat-absorbing reaction that chemically breaks down fuel into char, carbon dioxide, carbon monoxide, water vapor, highly combustible hydrocarbon vapors and gases, and particulate matter. Combustion—a heat releasing reaction that creates carbon dioxide and water—follows pyrolysis as the escaping hydrocarbon vapors released from the surface of the fuels burn (Ottmar 2001).

4.1.1. Phases of Combustion. The combustion of forest fuels during a fire can be broken down into four phases: [1] pre-ignition, [2] flaming; [3] smoldering; and [4] glowing. During the pre-ignition phase, fuels ahead of the fire front are heated by radiation and convection. Water vapor is driven to the surface of the fuels and expelled into the atmosphere. As the fuel's internal temperature rises, cellulose and lignin—two main components of wood—begin to decompose, releasing combustible organic gases and vapors. Since these gases and vapors are extremely hot, they rise and mix with oxygen in the air and ignite at temperatures between 617° F and 662° F, leading to the flaming phase (Ottmar 2001).

In the flaming phase, fuel temperatures rise rapidly. Pyrolysis accelerates and is accompanied by flaming of the combustible gases and vapors. The predominant products of flaming combustion are carbon dioxide and water vapor. The water vapor is a product of the combustion process and the moisture being driven from the fuel. Temperatures during the flaming stage range between 932° F and 2552° F (Ottmar 2001).

During the smoldering phase, emissions of combustible gases and vapors above the fuel are too low to support flaming combustion, which results in a decrease in the spread of the fire and a significant drop in temperature. Peak smoldering temperatures range from 572° F to 1112° F. Near the end of the smoldering phase, the pyrolysis process nearly ceases, leaving the fuel that was not completely consumed with a layer of black char, high in carbon content (Ottmar 2001).

In the glowing phase, most volatile gases have been driven off. Oxygen in the air can now reach the exposed surface of char left from the flaming and smoldering phase and the remaining fuels begin to glow with a characteristic orange color. Peak temperatures of the burning fuel during the glowing phase are similar to those found in the smoldering phase and range from 572°F to 1117°F. Carbon dioxide, carbon monoxide, and methane are the principal products of glowing combustion. This phase continues until the temperature of the fuel drops or until only noncombustible, mineral gray ash remains (Ottmar 2001).

Although four phases of combustion have been identified, combustion of forest fuels is not an orderly, consistent progression through the phases. Changes in fuel and environmental conditions as a fire burns cause combustion to move between phases in a variety of directions and at a variety of rates. Conditions also can cause combustion to cease completely, leaving fuels unburned.

4.1.2. Combustion and Smoke Production. Fires burning in forest fuels, whether prescribed or wildland fires, emit a complex mixture of particles, liquids, and gases into the atmosphere, which collectively are called smoke (Chandler et al. 1983, Ottmar 2001, Ward 2001). All components of smoke from fires, with the exception of carbon dioxide and water, are generated by the incomplete combustion of biomass fuels.

Efficiency of combustion is an important determinant of both the composition and amount of smoke produced by a fire. Combustion efficiency is defined as the relative amount of time a fire burns in the flaming phase of combustion, as compared to the smoldering phase. Combustion efficiency also is used to describe the ratio of the amount of fuel that is consumed in the flaming phase compared to the amount of fuel consumed during the smoldering phase (National Wildfire Coordinating Group 1996). Both definitions reflect that a higher proportion of fuel carbon is converted to carbon dioxide during flaming than during smoldering. During smoldering a higher proportion of fuel carbon is emitted as particulate matter.

The flaming stage of combustion has a high combustion efficiency; therefore, it tends to emit the least emissions relative to the mass of fuel consumed. The smoldering stage has a low combustion efficiency and produces more smoke relative to the mass of fuel consumed (Ottmar 2001, Sandberg et al. 2002). Total emission rates are about eight times higher during the smoldering phase of a fire than during the flaming phase (Chandler et al.

1983), and particulate matter emissions generated per mass of fuel consumed during the smoldering phase is more than double that of the flaming phase (Ottmar 2001).

4.1.3. Determinants of Smoke Quantity. The amount of smoke produced by a forest fire is determined by the amount of fuel consumed in each combustion phase, as well as the size of the area burned, fuel characteristics, fire behavior, and combustion conditions (Ottmar 2001, Sandberg et al. 2002, Ward 2001). During a wildland fire, the amount of biomass consumed during the flaming phase of combustion can range from 20% and 90%, with the remainder occurring during the smoldering and glowing stages (Ottmar 2001). Fuel characteristics—including arrangement, distribution by size class, moisture, and chemistry—are the primary determinants of the duration of the flaming and smoldering combustion phases and combustion efficiency (Ward 2001).

Fuel type, fuel moisture content, arrangement, and, in the case of prescribed fires, the way the fuels are ignited can affect the amount of biomass fuels consumed during various combustion stages (Ottmar 2001, Sandberg et al. 2002, Ward 2001). These characteristics of fuels can vary widely between and within forests. Fuel types in forests may include grasses, shrubs, woody fuels, litter, moss, or duff. Fuels can be live or dead; woody fuels sound or rotten.

Each characteristic influences the way fuel burns and the emissions it produces. For example, smoldering combustion is more prevalent in certain types of fuel such as duff, organic soils, and rotten logs, due to the lack of oxygen necessary to support flaming combustion. Smoldering combustion is often less prevalent in fuels with high surface to volume ratios such as grasses, shrubs, and small diameter woody fuels (Ottmar 2001, Sandberg et al. 2002).

Fuel moisture content affects the flame temperature that in turn influences the ease of ignition, the amount and rate of combustion, and combustion efficiency. Generally, fuels with low moisture content burn more efficiently and produce fewer emissions per unit of fuel consumed (Ottmar 2001). Combustion of large woody fuels generally depends on the moisture content (Ottmar 2001).

The chemical composition of vegetation also affects the rate and efficiency of combustion and the emissions that are produced (Ward 2001). For example, fuels with a high resin content generally produce more smoke than fuels with less resin.

The spacing and arrangement of fuels affects the rate of burning and the efficiency of combustion. Sustained ignition and combustion will not occur when fuels are widely spaced. Loosely packed fuels provide a sufficient amount of oxygen available for combustion, but may result in inefficient heat transfer between burning and adjacent unburned fuels. Tightly packed fuels allow efficient heat transfer, but may restrict oxygen availability (Ottmar 2001).

Fire behavior is the manner in which fire reacts to the fuels available for burning and is dependent upon the type, condition, and arrangement of small woody fuels, local weather conditions, topography, and, in the case of prescribed fire, lighting pattern and rate. Fire behavior influences combustion efficiency and the resultant pollutants produced from wildland fires. For example, during fires with rapid rates of spread and high intensity but relatively short duration, a majority of the biomass consumed will be smaller woody fuels and will occur during the more efficient flaming period, resulting in fewer emissions. During wildland fires with a range of fire intensities and spread rates but long burning durations, a large portion of the biomass consumed will occur during the less efficient smoldering phase, producing more smoke relative to the fuel consumed (Ottmar 2001).

The ignition pattern also influences the amount of emissions (Chandler et al. 1983, Ward 2001). Ignition patterns are classified as backing, heading, and flanking fires. A backing fire is moving *into* the wind, a heading fire is moving *with* the wind, and a flanking fire is moving *perpendicular* to the wind (Martin 1990). Fuel characteristics and other conditions will affect how ignition patterns influence emissions. For example, in simple, uniform fuels, such as pine leaf litter with only shallow organic material beneath, a backing fire spreads slowly with low intensity, consuming fuel very efficiently and producing little smoke. In more complex fuel, the backing flame may become more turbulent, decreasing combustion efficiency, and thus producing more smoke emissions (Ottmar 2001).

4.1.4. Determinants of Smoke Composition. Many of the same factors that affect the amount of smoke produced from a fire also affect the composition of the smoke. Fuel chemistry is one of the primary determinants of the composition of smoke and leads to a wide diversity in the chemical content of emissions (Ward 2001). Wood is a complicated arrangement of cellulose, hemicellulose, and lignin, incorporated with a wide range of extractives (terpenes and resins), and mineral constituents

(Chandler et al. 1983). Different species of wood and other vegetation will combust differently, leading to emissions with different chemical compositions (Ottmar 2001).

Fire behavior, ignition pattern, and environmental conditions also are important determinants of the composition of emissions (Ward 2001). The proportion of emissions that is particulate matter varies markedly between flaming and smoldering combustion, with smoldering having a higher concentration (Chandler et al. 1983, Ward 2001). Low intensity fires produce proportionately higher amounts of particulate matter (Ward 2001).

4.2. Management Objectives for Prescribed Fires

Prescribed fires are used for a variety of resource management objectives, including:

- clearing land for conversion to another use,
- removing logging slash after timber harvesting operations,
- preparing sites and soils for reforestation or regeneration,
- reducing fuels that create hazardous fire conditions,
- thinning (i.e., reducing) tree density,
- controlling plant or tree species composition,
- controlling insects, diseases, or other pests,
- managing wildlife habitat,
- increasing forage for livestock or wildlife,
- managing water quantity and quality,
- improving aesthetics, and
- maintaining historic fire regimes as a part of ecosystem maintenance (Chandler et al. 1983, Lindeburgh 1990, Martin 1990, Norris 1990, Pyne 1984, Wright and Bailey 1982).

The management objectives for a prescribed fire will influence the way it is planned and carried out, including: the weather and moisture conditions under which the fire is lit, the pattern of ignition (i.e., backing, heading, or flanking fire), the amounts and types of vegetation that are targeted for burning, and the intensity with which the fire is allowed to burn. Every prescribed fire has a unique prescription based on its management objectives (Martin 1990), and management objectives may vary for each prescribed fire (Wright and Bailey 1982).

The list of techniques for reducing emissions in the following section (section 4.3) focuses on techniques that reduce emissions from prescribed fire without regard to a particular management objective. We identify techniques that may not be compatible with reducing emissions from subsequent wildland fires, but are included because

they may be useful for reducing emissions from prescribed fires that serve other purposes.

4.3. Reducing Emissions from Fires

Techniques are available that under the right circumstances can reduce emissions from a given prescribed burn area by as much as 60% (Ottmar et al. 2001). If emission reduction techniques were used optimally nationwide, researchers estimate that emissions could probably be reduced by 20-25% assuming all other factors (vegetation types, acres, etc.) were held constant and land management goals were still met (Ottmar et al. 2001). Variability in reductions between individual states or regions is likely to be high due to variations in biological decomposition capability and other ecological factors (Ottmar et al. 2001; Peterson and Leenhouts 1997).

Emission reduction techniques can be used independently or in combination on any given burn. Any one of the techniques may or may not be applicable in a given situation depending upon specifics of the fire use objectives, project locations, time and cost constraints, weather and fuel conditions, and public and firefighter safety considerations (Ottmar et al. 2001).

No two burns are the same in terms of pollutant emissions, smoke impacts, fuel consumption, or other parameters (Ottmar et al. 2001). The following sections summarize the seven general categories that encompass all of the emission reduction techniques described by Ottmar et al. (2001).

4.3.1. Reduce the Area Burned. The area burned can be reduced by burning a smaller area within a designated project area than originally planned, or simply by not burning at all. Reducing the area burned should be accomplished by methods that truly result in reduced emissions over time rather than a deferral of emissions to some future date (Ottmar et al. 2001). Reducing the area burned can have negative effects on ecosystem function in fire-adapted forest types and is least applicable when fire is needed for purposes related to ecosystem management or forest health enhancement (Ottmar et al. 2001).

Examples of specific techniques to reduce burn area include (Ottmar et al. 2001):

- **Burn Concentrations.** Sometimes fuels can be concentrated, through raking, piling or some other technique, and burned, rather than using fire on the whole area requiring treatment. The fuel loading of the areas burned using this technique tends to be high. The total area burned under these

circumstances can be very difficult to quantify (Ottmar et al. 2001).

- **Isolate fuels.** Large logs, snags, deep pockets of duff, sawdust piles, and other concentrations of fuel that have the potential to smolder for long periods of time can be isolated from burning. This can be accomplished by several techniques including: [1] constructing a fireline around the fuels of concern, [2] not lighting individual or concentrated fuels, [3] using natural barriers or snow, [4] scattering the fuels, and [5] spraying with foam or other fire retardant material. Eliminating these fuels from burning is often faster, safer, and less costly than mop-up, and leaves them intact following the prescribed burn (Ottmar et al. 2001).
- **Mosaic burning.** Landscapes often contain a variety of fuel types that are not continuous and vary in fuel moisture content. Prescribed fire prescriptions and lighting patterns can be assigned to use differences in fuel and fuel moisture to mimic a wildland fire and create patches of burned and non-burned areas or burn only selected fuels. Areas or fuels that do not burn do not contribute to emissions (Ottmar et al. 2001).

4.3.2. Reduce Fuel Load. Fuel load is the amount of fuel on a site (National Wildfire Coordinating Group 1996). Some or all of the fuel can be permanently removed from the site, biologically decomposed, or prevented from being produced. Overall emissions can be reduced when fuel is permanently excluded from burning by several techniques (Ottmar et al. 2001):

- **Mechanical removal.** Mechanically removing fuels from a site can potentially reduce emissions proportional to the amount of fuel removed, assuming other characteristics and conditions that affect burning remain the same (see section 4.1.3). Techniques include mechanical removal of logging debris following timber harvest or thinning operations, onsite chipping of woody material and brush for offsite utilization, and mechanical removal of fuels which can be followed by offsite burning in a more controlled environment. Sometimes mechanical treatments, such as whole-tree harvesting or yarding of unmerchantable material, may result in sufficient treatment

so that burning is not needed (Jones & Stokes 2004, Ottmar et al. 2001).

- **Mechanical processing.** Mechanical processing of dead and live vegetation into wood chips or shredded biomass is effective in reducing emissions if the material is removed from the site or biologically decomposed. Use of this technique may eliminate the need to burn. However, if the processed biomass is spread across the ground, rather than removed from the site, and becomes additional fuel for either a prescribed or wildland fire, emission reductions are not achieved (Jones & Stokes 2004, Ottmar et al. 2001).
- **Firewood sales.** Firewood sales may result in sufficient removal of woody debris making onsite burning unnecessary. This technique is particularly effective for piled material where the public has easy roadside access (Ottmar et al. 2001).
- **Biomass for electrical generation.** If conversion facilities exist, woody biomass can be removed and used to provide electricity. Combustion efficiency in electricity production is greater than open burning, resulting in less emissions from the biomass consumed (Ottmar et al. 2001).
- **Biomass utilization.** Woody material can be used for many miscellaneous purposes including pulp for paper, methanol production, wood pellets, garden bedding, and specialty forest products. Demand for these products varies widely from place to place and year to year (Ottmar et al. 2001).
- **Ungulate grazing.** Sheep, cattle, or goats can reduce fuels prior to burning or reduce the burn frequency by grazing and browsing live grassy or brushy fuels (Ottmar et al. 2001). Grazing can be an effective technique in the wildland-urban interface and rural residential areas where more grassy and brushy fuels may exist and there may be resistance to the use of prescribed fire (Jones & Stokes 2004).

4.3.3. Reduce Fuel Production. Management techniques can be used to shift species composition to vegetation types that produce less biomass per acre per year, or produce biomass that is less likely to burn or burns more efficiently with less smoke (Ottmar et al. 2001):

- **Chemical treatments.** Broad spectrum herbicides can be used to reduce or remove live vegetation. Selective herbicides can be

used to alter species diversity. Herbicides often can reduce or eliminate the need to use fire. Herbicides have their own set of drawbacks including regulatory requirements, possible adverse effects on water quality, harm to non-targeted species, and negative public opinion (Jones & Stokes 2004, Ottmar et al. 2001).

- **Site conversion.** Natural site productivity can be decreased by changing the vegetation composition. Total fuel loading can also be reduced through conversion to species that are less productive (Ottmar et al. 2001).
- **Land use change.** Changing forest lands to another land use category may result in elimination of the need to burn. However, conversion of forested sites to agriculture or urbanized uses significantly alters the land's ecological structure and function and raises numerous other philosophical and policy issues (Ottmar et al. 2001).

4.3.4. Reduce Fuel Consumed. Consumption is the amount of fuel removed from a site by burning (National Wildfire Coordinating Group 1996). Because fuel consumption is largely dependent on moisture content, if significant amounts of fuel are above the moisture content at which a fire will not propagate itself, fuels are unavailable for combustion and emissions are reduced (National Wildfire Coordinating Group 2001, Ottmar et al. 2001). But this may be temporary. Burning when fuels are wet may leave fuels in the treated area. These residual fuels may burn in the future, resulting in only a delay in emissions, not a reduction. Actual emission reductions over time are achieved only if the fuels left behind will biologically decompose or are otherwise treated to reduce emissions when they do burn. Even though wet fuels burn less efficiently and produce greater amounts of emissions than the same quantity of dry fuels, emissions from a given fire can be significantly reduced because less fuel is consumed (Ottmar et al. 2001).

The ability to target and burn only the fuels necessary to meet management objectives is one of the most effective methods of reducing emissions. Limiting large fuel and organic layer consumption with the following techniques can significantly reduce emissions (Ottmar et al. 2001):

- **High moisture in large woody fuels.** Burning when large-diameter woody fuels (3 or more inches in diameter) are wet can result in lower fuel consumption and less smoldering. This can be a very effective technique for reducing total emissions from

a prescribed burn area. However, when consumption of large-diameter fuel is needed, burning under high moisture conditions is not a viable alternative (Ottmar et al. 2001).

- **Moist litter and/or duff.** The organic layer on the forest floor comprised of decayed and partially decayed material often burns during the inefficient smoldering phase of combustion. Consequently, reducing the consumption of this material can be very effective at reducing emissions. Consumption of the litter and/or duff layer can be greatly reduced if the material is moist (Ottmar et al. 2001).
- **Burn before precipitation.** Scheduling a prescribed fire before an imminent precipitation event will often limit the consumption of large woody material, snags, stumps, and organic ground matter, thus reducing the potential for a long smoldering period and increased emissions. Successful application of this procedure obviously depends on accurate weather forecasts for the burn area (Ottmar et al. 2001).
- **Burn before large fuels cure.** The fuel moisture content of living trees is very high. If an area can be burned within three to four months after timber harvest, many of the large fuels will still contain a significant amount of live fuel moisture. This technique is generally restricted to forest fuels generated as a by-product of management activities (Ottmar et al. 2001).

4.3.5. *Schedule Burning Before New Fuels Appear.*

Burning can sometimes be scheduled for times of the year before new fuels appear. This may interfere with land management goals if burning is forced into seasons and moisture conditions where increased mortality of desirable species can result (Ottmar et al. 2001).

- **Burn before litter fall.** When deciduous trees and shrubs drop their leaves this ground litter contributes extra fuel. If burning takes place prior to litter fall there is less available fuel and therefore less fuel consumed and fewer emissions (Ottmar et al. 2001).
- **Burn before green-up.** Burning in cover types with a grass and/or herbaceous fuel component can produce fewer emissions if burning takes place before these fuels green-up for the year. Less fuel is available

therefore fewer emissions are produced (Ottmar et al. 2001).

4.3.6. Increase Combustion Efficiency. Research has shown that the amounts of all pollutants emitted from forest fires, except nitrous oxide, are negatively correlated with combustion efficiency (National Wildfire Coordinating Group 2001; Ottmar et al. 2001, Ward and Hardy 1991). Therefore, actions that result in lower emissions of one pollutant into the air result in the reduction of all pollutants into the air, except nitrous oxide (Ottmar et al. 2001). Increasing combustion efficiency, or shifting consumption away from the smoldering phase and into the more efficient flaming phase, reduces emissions (Ottmar et al. 2001).

- **Burn piles or windrows.** Fuels concentrated into clean and dry piles or windrows generate greater heat and burn more efficiently. Concentrating fuels into piles or windrows generally requires the use of heavy equipment, which can negatively impact soils and water quality. Piles and windrows also cause temperature extremes in the soils directly underneath and can result in areas of soil sterilization. If fuels in piles or windrows are wet or mixed with dirt, extended smoldering of the debris can result in residual emission problems (Ottmar et al. 2001).
- **Backing fires.** A backing fire generally consumes more fuel in the flaming phase of consumption than a heading fire used to burn the same fuels (Ottmar et al. 2001).
- **Dry conditions.** Burning under dry conditions increases combustion efficiency. However, drier conditions may make more fuels available to burn. The emissions from additional fuel burned generally more than offsets emission reduction advantages gained by greater combustion efficiency (Ottmar et al. 2001).
- **Rapid mop-up.** Rapidly extinguishing a fire can reduce fuel consumption and smoldering emissions somewhat. This technique, however, is not particularly effective at reducing total emissions and can be very costly. Rapid mop-up is more effective as an avoidance technique by reducing residual emissions that tend to get caught in drainage flows and end up in smoke sensitive areas (Ottmar et al. 2001).
- **Aerial ignition/mass ignition.** Mass ignition lights a fire over a large area in a short amount of time. Helitorching—using a

helicopter with a large drip torch attached—is a common technique. Mass ignition can shorten the duration of the smoldering phase of a fire and reduce the total amount of fuel consumed. When properly applied, mass ignition causes rapid consumption of dry, surface fuels and creates a very strong plume or convection column which draws much of the heat away from the fuelbed and prevents drying and preheating of larger, moister fuels (Ottmar et al. 2001).

- **Air curtain incinerators.** Burning fuels in a large metal container or pit with the aid of a powerful fan-like device to force additional oxygen into the combustion process results in a very hot and efficient fire that produces little smoke. In areas sensitive to smoke, these devices are commonly used to burn debris from land clearing, highway right-of-ways, or building demolition (Ottmar et al. 2001).

4.4. Redistributing Emissions

Emissions can be spatially and temporally redistributed by burning during periods of good atmospheric dispersion (dilution) and when prevailing winds will transport smoke away from sensitive areas (avoidance) so that air quality standards are not violated (Hardy and Leenhouts 2001, Sandberg et al. 2002). Redistribution of emissions does not necessarily reduce overall emissions (Ottmar et al. 2001).

4.4.1. Burn When Dispersion is Good. Smoke concentrations can be reduced by diluting the smoke through a greater volume of air, either by burning during good dispersion conditions when the atmosphere is unstable or burning at slower rates. If burning progresses too slowly, smoke accumulation due to evening atmospheric stability can occur (Ottmar et al. 2001).

Meteorological scheduling is often the most effective way to minimize direct smoke impacts to the public (Ottmar et al. 2001). Numerous tools for helping fire practitioners with meteorological scheduling have been or are being developed (see section 4.6). For example, some researchers suggest using clouds as part of the prescription for scheduling prescribed fires because cloud formation and precipitation processes are mechanisms by which the atmosphere is cleansed of particulate matter and the other components of smoke (EPA 2004e, Radke et al. 2001).

4.4.2. Share the Airshed. Establishing a smoke management program that links both local and interstate jurisdictions will create opportunities to share the airshed and reduce the likelihood of smoke impacts (Ottmar et al. 2001). Idaho's smoke management program (SMP) takes such an approach (see section 3.7).

4.4.3. Avoid Sensitive Areas. The most obvious way to avoid smoke impacts is to burn when the wind is blowing away from smoke-sensitive areas such as highways, airports, populated areas, and scenic vistas. Wind direction must be considered during all phases of burning (Ottmar et al. 2001).

4.4.4. Burn Smaller Units. Short term emissions and impacts can be reduced by burning subsets of a large unit over multiple days. Total emissions are not reduced if the entire area is eventually burned, but the effects are spread over a longer time period (Ottmar et al. 2001).

4.4.5. Burn More Frequently. Burning more frequently does not allow fuels to accumulate. Frequent, low intensity fires can prevent unwanted vegetation from becoming established. If longer fire rotations are used, vegetation has time to grow, resulting in the production of more biomass and more fuel loading at the time of burning. This technique may help meet land management goals where frequent fires closely mimic historic fire conditions (Ottmar et al. 2001).

4.5. Smoke Reduction and Redistribution Techniques in the Intermountain Region

Reducing or redistributing emissions from fires may be only one of many goals that a forest manager wishes to or must achieve through his or her management actions. Often other goals or constraints preclude the use of a technique to reduce emissions. In some cases, however, smoke emission reductions are of great importance and are achieved by compromising other goals. Emission reduction techniques vary widely in their applicability and effectiveness by vegetation type, burning objective, region of the country, and whether fuels are natural or generated as a by-product of management activities (Ottmar et al. 2001).

The overall potential for emission reductions from prescribed fire depends on the frequency of use of each emission reduction technique and the amount of emission reduction that each method offers (Ottmar et al. 2001). The use of each emission reduction technique is influenced by numerous factors including land management objectives, the

type and amount of vegetation being burned, geography, safety considerations, costs, laws and regulations (Ottmar et al. 2001).

The assessment of the use and effectiveness of each emission reduction and redistribution technique presented here is based on input from fire practitioners who participated in a series of workshops in 1999 (Ottmar et al. 2001). Table 4-1 summarizes how frequently each of the 29 smoke management methods described in Ottmar et al. (2001) is used in the intermountain region, which includes Idaho, Montana, Wyoming, and Colorado. Of the 13 techniques with a high emission reduction potential (Table 4-2), five are commonly used in the region (Table 4-1).

Table 4-2 describes the general effectiveness of the emission reduction and redistribution techniques based on input from managers at the workshops (Ottmar et al. 2001). Each technique was assigned a general rank of “High” for those techniques most effective at reducing emissions or “Low” for those techniques that are less effective. Some emission reduction techniques also have secondary benefits of delaying or eliminating the need to use prescribed fire. Some smoke management techniques are also effective for reducing local smoke impacts if they promote plume rise or decrease the amount of residual smoldering combustion where smoke is more likely to get caught in drainage winds and carried into populated areas (Ottmar et al. 2001). These factors are also addressed in Table 4-2.

Table 4-3 summarizes significant constraints identified by fire managers that limit the wider application of techniques to reduce and redistribute emissions. This table excludes consideration of the objective of the burn, which is generally the overriding constraint. Some of the techniques would probably be used more frequently if the listed constraints could be overcome (Ottmar et al. 2001). Smoke management techniques that, in the opinion of workshop participants, show promise for wider use in the future are: mosaic burning, mechanical removal, high moisture in large woody fuels and/or moist litter and duff, pile and windrow burning, aerial/mass ignition, and burn more frequently (Ottmar et al. 2001).

Emission reduction techniques are not without negative consequences and must be prescribed and used with careful professional judgment and full awareness of possible tradeoffs. Emission reduction techniques alter fire behavior and fire effects and can impair or prevent accomplishment of land management objectives. Emission reduction techniques can cause negative effects on other valuable resources such as through soil compaction,

loss of nutrients, impaired water quality, and increased tree mortality. Land managers must weigh the impact of their decisions on long-term ecosystem productivity and processes (Ottmar et al. 2001).

4.6. New Tools for Managing Smoke and Air Quality

Modeling is an important tool that can help evaluate different approaches for managing smoke from fires. For example, models such as the Fire Effects Tradeoff Model (FETM) can help managers determine the long-term consequences on vegetation and emissions of using prescribed fire. FETM is a disturbance effects model designed to simulate the tradeoffs between alternative land management practices over periods of time up to 300 years and under diverse environmental conditions, natural fire regimes, and fuel and fire management strategies (USFS 2003).

Models that estimate the amount of emissions released by wildland and prescribed fires have been around for several years. For example, CONSUME is a model and computer application used to estimate the amount of fuel consumed and pollutant emissions produced by a prescribed or wildland fire. It is a decision-making tool designed to assist land managers in achieving prescribed fire objectives while minimizing the impacts on air quality, soil, water, wildlife, and other resources. CONSUME was developed in the 1980s in the Pacific Northwest and has been updated and upgraded (Ottmar et al. 2002, Calvin 2002). CONSUME was used by researchers to estimate emissions reductions from treatment scenarios for the Boise National Forest in Idaho (Neuenschwander and Sampson 2000).

More recent modeling efforts have begun to focus on meteorology and the scheduling of prescribed fires at times when smoke dispersion is good and/or when smoke will be carried away from sensitive areas. Many of these efforts are coordinated through the Fire Consortia for Advanced Modeling of Meteorology and Smoke (USFS 2004d). The Northwest Regional Modeling Consortium, a part of the national consortium, is working on a high-resolution weather prediction system for smoke dispersion throughout the northwestern U.S. region. The Idaho Department of Environmental Quality is a contributing member of the consortium (NRMC 2004).

The USDA Forest Service also is involved in numerous modeling projects. At the Pacific Northwest Research Station, the AirFire Team focuses on understanding the role of weather and fire in ecological disturbance and develops decision tools for ecosystem management, fire operations,

Table 4-1. Frequency of use for each smoke management technique in the intermountain region, which includes Idaho, Montana, Wyoming, and Colorado.

Smoke Management Technique	Frequency of Use in Intermountain Region		
	Rarely	Occasionally	Commonly
1. Reduce the Area Burned			
• Burn Concentrations			✓
• Isolate Fuels			✓
• Mosaic Burning			✓
2. Reduce Fuel Load			
• Mechanical Removal			✓
• Mechanical Processing		✓	
• Firewood Sales	✓		
• Biomass for Electrical Generation	✓		
• Biomass Utilization	✓		
• Ungulates			✓
3. Reduce Fuel Production			
• Chemical Treatment	✓		
• Site Conversion	✓		
• Land Use Change	✓		
4. Reduce Fuel Consumed			
• High Moisture in Large Woody Fuels		✓	
• Moist Litter & Duff		✓	
• Burn Before Precipitation		✓	
• Burn Before Large Fuels Cure	✓		
5. Schedule Burning Before New Fuels Appear			
• Burn Before Litter Fall	✓		
• Burn Before Green-up		✓	
6. Increase Combustion Efficiency			
• Burn Piles & Windrows			✓
• Backing Fires	✓		
• Dry Conditions	✓		
• Rapid Mop-up		✓	
• Aerial Ignition / Mass Ignition			✓
• Air Curtain Incinerators	✓		
7. Redistribute emissions			
• Burn When Dispersion is Good			✓
• Share the Airshed			✓
• Avoid Sensitive Areas			✓
• Burn Smaller Units	✓		
• Burn More Frequently		✓	

Source: Ottmar et al. 2001

Table 4-2. Relative effectiveness of various smoke management techniques.

Smoke Management Techniques	General Emission Reduction Potential	Can Eliminate or Delay Need to Burn	Effective for Local Smoke Impact Reduction (if burned)
1. Reduce the Area Burned			
• Burn Concentrations	High		✓
• Isolate Fuels	High		✓
• Mosaic Burning	High		
2. Reduce Fuel Load			
• Mechanical Removal	High	✓	
• Mechanical Processing	Low	✓	
• Firewood Sales	Low	✓	
• Biomass for Electrical Generation	High	✓	
• Biomass Utilization	Low	✓	
• Ungulates	High	✓	
3. Reduce Fuel Production			
• Chemical Treatment	Moderate	✓	
• Site Conversion	High	✓	✓
• Land Use Change	High	✓	
4. Reduce Fuel Consumed			
• High Moisture in Large Woody Fuels	High		✓
• Moist Litter & Duff	High		✓
• Burn Before Precipitation	High		✓
• Burn Before Large Fuels Cure	High		✓
5. Schedule Burning Before New Fuels Appear			
• Burn Before Litter Fall	Low		
• Burn Before Green-up	Low		
6. Increase Combustion Efficiency			
• Burn Piles & Windrows	Low		✓
• Backing Fires	Moderate		✓
• Dry Conditions	Low		
• Rapid Mop-up	Low		✓
• Aerial Ignition / Mass Ignition	Low		✓
• Air Curtain Incinerators	High		✓
7. Redistribute emissions			
• Burn When Dispersion is Good	None		✓
• Share the Airshed	None		✓
• Avoid Sensitive Areas	None		✓
• Burn Smaller Units	None		✓
• Burn More Frequently	None		✓

Source: Ottmar et al. 2001

Table 4-3. Constraints to use of smoke management techniques.

Smoke Management Technique	Constraints				
	Administrative	Physical	Legal	Cost	Other
1. Reduce the Area Burned					
• Burn Concentrations	Few	Slope & access	Few	High	Only applicable to small pockets of fuel
• Isolate Fuels	Few	Slope	Few	High	Incompatible fuels
• Mosaic Burning	Few	Few	Few	Moderate	Incompatible fuels
2. Reduce Fuel Load					
• Mechanical Removal	Moderate	Slope	Few	Moderate	Slope
• Mechanical Processing	Moderate	Slope & access	Few	High	Incompatible fuels
• Firewood Sales	High	Access	High	Few	No markets, incompatible fuels
• Biomass for Electrical Generation	High	Slope & access	Moderate	High	No markets, incompatible fuels
• Biomass Utilization	High	Slope & access	Moderate	High	No markets, incompatible fuels
• Ungulates	Few	Few	High	High	Incompatible fuels
3. Reduce Fuel Production					
• Chemical Treatment	High	Few	Very High	Very High	Controversial policy, adverse water quality impacts
• Site Conversion	High	Few	High	High	Ecosystem impacts
• Land Use Change	Very High	Few	Very High	Very High	Ecosystem impacts
4. Reduce Fuel Consumed					
• High Moisture in Large Woody Fuels	Few	Few	Few	Few	Incompatible fuels in some regions
• Moist Litter & Duff	Few	Few	Few	Few	Not used in SW region
• Burn Before Precipitation	Few	None	None	Few	Difficult to plan
• Burn Before Large Fuels Cure	Few	Few	Few	Few	Limited to activity fuels, incompatible fuel types
5. Schedule Burning Before New Fuels Appear					
• Burn Before Litter Fall	Few	Few	None	Few	Incompatible fuels in most regions
• Burn Before Green-Up	Few	Slope	Few	Few	Limited use in many fuel types

(continued)

Table 4-3. (continued)

Smoke Management Technique	<u>Constraints</u>			
	Administrative	Physical	Legal	Cost
6. Increase Combustion Efficiency				
• Burn Piles & Windrows	Few	Slope	Few	High
• Backing Fires	Few	Fuel continuity	Few	Few
• Dry Conditions	High	Dry conditions	High	High
• Rapid Mop-up	Few	Slope & access	Few	High
• Aerial Ignition / Mass Ignition	Few	Few	Few	Moderate
• Air Curtain Incinerators	Few	Access	Few	Very High
7. Redistribute emissions				
• Burn When Dispersion is Good	Few	Moderate	Few	Moderate
• Share the Airshed	High	Few	High	High
• Avoid Sensitive Areas	Few	Moderate	Few	High
• Burn Smaller Units	High	Few	Few	High
• Burn More Frequently	Few	Few	Few	Moderate

Source: Ottmar et al. 2001

Need correct meteorological conditions
 Increased escape potential
 Trained crews and equipment; fuel types
 Increased escape potential
 Smoke management windows and cost

planning, and smoke management (USFS 2004b). Also at the Pacific Northwest Research Station is the Fire and Environmental Research Applications Team (FERA). Their mission includes research into air quality and smoke management, particularly modeling (USFS 2004c).

Among FERA's modeling projects is BlueSkyRAINS. BlueSky is a product that links computer models of fuel consumption and emissions, fire, weather, and smoke dispersion into one system for predicting the cumulative impacts of smoke from prescribed fire, wildland fire, and agricultural fire. Every night BlueSky obtains a regional meteorological forecast and burn information from state and federal agency burn reporting systems. The merging of these data with fuel consumption and emission models and dispersion and trajectory models results in a regional forecast of smoke concentrations for the next two days.

RAINS is the Rapid Access Information System developed by Region 10 of the U.S. Environmental Protection Agency in the Pacific Northwest, which includes Idaho.

RAINS utilizes geographical information system (GIS) technology to give the user a web-based window where he or she can overlay data layers of interest (topography, census data, Class I wilderness areas, etc.), zoom and pan around the domain, and query a database for additional data regarding the various layers (USFS and EPA 2004).

BlueSkyRAINS merges the technology of RAINS with the smoke dispersion information from BlueSky to create an interactive web-based regional forecast of smoke concentrations and trajectories. Land managers, regulators, and the general public can use BlueSkyRAINS to view the potential smoke impacts from regional burning activities (USFS and EPA 2004).

BlueSkyRAINS is one among several smoke dispersion prediction systems that are becoming increasingly valuable tools in smoke management (Ferguson 2001). These prediction models are increasing the abilities of agencies and burners to plan and cooperate across regions and are changing the way smoke and fires are managed (USFS and EPA 2004).

Chapter 5. Conclusions

The condition of many of Idaho's forests today, especially the national forests that dominate the forest landscape in the state, make them more susceptible to larger, more frequent, and more intense fires than those that occurred historically, putting many of the values of these forests at risk (O'Laughlin and Cook 2003). Reintroducing fire into some forests through prescribed burning will help protect their long-term sustainability. However, one of the short-term effects of prescribed fires is smoke, and smoke has adverse health and welfare effects on people. The federal Clean Air Act is designed to protect people from the harmful effects of smoke and other air pollutants.

Can prescribed fire reduce subsequent wildland fire smoke emissions? The question has two dimensions that we have addressed, one related to physical science and the other to policy.

The physical dimension is more specifically expressed by another question: For a given forest over a given time frame, are total emissions less from one prescribed fire—or a series of prescribed fires—than they would if the same area was allowed to burn via wildland fire? Our reply is: yes, probably. In order to increase the likelihood of the prescribed fire emissions being less than the wildland fire emissions, the prescribed fires need to take place under fuel and fire conditions that tend to lessen emissions.

Many factors interact to influence the amount of emissions a fire produces, including fuel abundance, fuel type, fuel size, fuel chemistry, fuel moisture, fire ignition pattern, fire temperature, fire behavior, and fire duration (see section 4.1). Fire prescriptions can be designed to control emissions by managing these factors, but that does not guarantee that emissions will be less than they might be during a wildland fire in the future. For example, a fast-moving, high-intensity wildland fire burning when fuels are relatively dry may produce less emissions than a slow-moving, low-intensity prescribed fire burning when fuels are relatively moist. A wildland fire that burns more fuel, but burns much of it in the flaming phase of combustion, may produce fewer emissions than a prescribed fire that burns less fuel, but burns much of it in the smoldering phase of combustion. Smoke production depends on the conditions under which a fire takes place, and no two fires are exactly alike.

Prescriptions for fires can be created to control emissions. However, emissions control may be only one of many objectives that a prescribed fire is

designed to achieve, and emissions control may not be compatible with other, more important objectives.

There are many techniques available that can reduce emissions from forest fires regardless of whether a prescribed fire or wildland fire burns the forest (see section 4.3). Emissions are ultimately limited by the amount of fuel that burns, and techniques that directly reduce the amount of fuel that is available to burn are very effective.

One advantage prescribed fire has over wildland fire is that the timing of the fire is controlled. Managers then not only have more control over the physical factors that produce emissions, but also can respond to favorable meteorological conditions that contribute to dispersion of the emissions. The same amount of emissions can have less impact on humans and their habitations if dispersion conditions are good rather than if they are bad. Managers also can coordinate ignitions of prescribed fires across an airshed so that total emissions in the airshed are controlled.

The policy dimension of the question—Can prescribed fire reduce subsequent wildland fire emissions?—is more specifically expressed by another question: Do the laws and regulations that protect air quality allow for increased smoke from prescribed fires in the short-term in order to prevent worse air quality from unplanned wildland fires in the future? Our reply is yes.

The Clean Air Act itself does not address directly whether the smoke from prescribed fires for resource benefits ought to be regulated differently than smoke from wildland fires. The statute does not address how the short-term effects and risks of some smoke from prescribed fires ought to be weighed against the longer-term risk of more, uncontrolled smoke from wildland fires in the future. Instead, the U.S. Environmental Protection Agency (EPA), which administers the Act, is empowered to make distinctions in how smoke from prescribed fires and wildland fires is treated under the law.

Under EPA's natural events policy (Nichols 1996), emissions from wildland fires that contribute to violations of the PM₁₀ National Ambient Air Quality Standards (NAAQS) do not result in nonattainment status if the emissions are caused by "natural events" and a state has plans to control other sources of emissions during these events. If wildland fires in Idaho and the rest of the western U.S. continue to increase in frequency and intensity, the smoke from them may force more frequent and stringent controls on other activities that also produce emissions, including prescribed fires. The natural events policy also applies to the newly implemented PM_{2.5} NAAQS (Wegman 2004).

The *Interim Air Quality Policy on Wildland and Prescribed Fire* (EPA 1998) allows the EPA to exercise increased discretion if violations of air quality standards are caused by prescribed fires being used to maintain healthy forests. This policy represents an advance in the understanding between air quality regulators and forest managers about the role of fire and need for prescribed fire in some forest types.

Both the natural events policy and the *Interim Air Quality Policy on Wildland and Prescribed Fire* are lenient with violations of particulate matter NAAQS due to forest fire smoke, provided that a state has a natural events action plan (NEAP) and a smoke management program (SMP) in place. Idaho has both. Whether this leniency will continue if wildland fires and the use of prescribed fires increase remains to be seen.

While both the natural events policy and the interim policy on wildland and prescribed fire may be sufficient for addressing forest fire emissions, neither policy has the legal standing of a statute or administrative rule. A more permanent policy set through legislation or administrative rule making might provide more surety to states that implement many of the Clean Air Act's provisions.

The EPA also recognizes that smoke from forest fires can be a multi-state or regional problem; smoke does not stop at state boundaries. The EPA encourages states to work together to develop and implement smoke management programs (SMPs), as Montana and Idaho have done. The EPA also encourages states to work together to implement the administrative rules for controlling regional haze. Although multi-state cooperative efforts sometimes can be cumbersome, they are necessary to effectively deal with air quality issues related to forest fires.

The relationship between the EPA and the states in implementing the Clean Air Act is not without controversy however. For example, the Western Governors' Association has a series of recommendations for the EPA that would improve the State Implementation Plan process (WGA 1997). States are also facing financial and administrative difficulties in implementing the regional haze administrative rules (WESTAR 2003).

If prescribed fire is to become a more prevalent tool in Idaho's forests, air quality managers and

forest managers will have to work together to improve their understanding of the effectiveness, options, difficulties, applicability, and tradeoffs of different emission reduction techniques (Ottmar et al 2001). Some effective techniques are currently underutilized for a variety of administrative, financial, and other reasons. Constraints to the use of prescribed fire may need to be reexamined.

The general public may also have to become more tolerant of smoke in the air during times that are appropriate for prescribed fires. People's understanding of the tradeoffs between smoke now and smoke later needs to be increased, which compels land managers to learn how to explain the tradeoffs regarding smoke and to better understand public opinion about management options (Shindler and Toman 2003). Forest managers need to provide a consistent message to the public about the role of fire and its hazards and risks (USDI et al. 2001).

Two areas seem ripe for further investigation. First is the ability to identify the sources of smoke emissions at the airshed scale. This seems particularly appropriate in Idaho, where different rules govern smoke from prescribed fire in forests and other human-ignited burning. Smoke from other sources may be inaccurately attributed to prescribed fires.

A second promising research area is combined efforts on the capabilities of meteorological scheduling and smoke prediction models. Improved predictions of smoke quantity and movements could be used to determine how to decrease smoke impacts on human health and visibility (Reinhardt et al. 2001, Riebau and Fox 2001, White 2004).

Prescribed fires have the capability of restoring or maintaining the historic ecological conditions in many of Idaho's forests, while reducing future chances of uncontrolled wildland fires with uncharacteristically severe effects. Prescribed fires can be managed to reduce the amount of smoke produced and distribute it in ways that impact people less than wildland fires do. Air quality policies allow for regulatory differences in the ways wildland fire smoke and prescribed fire smoke are treated. The remaining question is public willingness to accept increased amounts of prescribed fire smoke now to avoid larger amounts of wildland fire smoke in the future. The answer is unclear (Brunson and Shindler 2004, Shindler and Toman 2003).

References Cited

- Arno, S.F. 2000. Fire in western forest ecosystems. Pages 97-120 in *Wildland Fire on Ecosystems: Effects of Fire on Flora, Volume 2*, J.K. Brown, J.K. Smith, eds. General Technical Report RMRS-GTR-42-vol. 2. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT. Available online: <http://www.fs.fed.us/rm/pubs/rmrs_gtr42_2.html> [19 April 2004].
- _____, and S. Allison-Bunnell. 2002. *Flames in Our Forests: Disaster or Renewal?* Island Press, Washington, DC.
- Battye, R., B. Bauer, and G. MacDonald. 1999. *Features of Prescribed Fire and Smoke Management Rules for Western and Southern States*. Available online: <<http://www.wrapair.org/forums/fejf/documents/woodard.pdf>> [5 February 2004].
- Brunson, M.W., and B.A. Shindler. 2004. Geographic variation in social acceptability of wildland fuels management in the western United States. *Society and Natural Resources* 17:661-678.
- Calvin, M. 2002. *CONSUME 3.0 System Design*. Available online: <<http://www.fs.fed.us/pnw/fera/publications/fulltext/consume/CONSUME3DesignCompleteV3.pdf>> [3 May 2004].
- Chandler, C., P. Cheney, P. Thomas, L. Trabaud, and D. Williams. 1983. *Fire in Forestry*. John Wiley & Sons, Inc., New York, NY.
- Core, J.E. 2001. Visibility. Pages 35-40 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, and J.L. Peterson. 2001. Public health and exposure to smoke. Pages 27-33 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- EPA (U.S. Environmental Protection Agency). 1992. *Prescribed Burning Background Document and Technical Information Document for Prescribed Burning Best Available Control Measures*. EPA-450/2-92-003, Office of Air Quality Planning, Research Triangle Park, NC. Available online: <<http://www.epa.gov/ttncaaa1/t1/reports/pbtid.exe>> [10 November 2004].
- _____. 1998. *Interim Air Quality Policy on Wildland and Prescribed Fire*. Issued April 23, 1998. Available online: <<http://www.epa.gov/ttn/oarpg/t1/memoranda/firefnl.pdf>> [10 December 2003].
- _____. 2004a. SIP-Idaho Table of Contents. Available online: <<http://yosemite.epa.gov/r10/AIRPAGE.NSF/03a8cf19962deac5a88256b2f007f7896?OpenDocument>> [26 January 2004].
- _____. 2004b. Green Book. Available online: <<http://www.epa.gov/oar/oaqps/greenbk/>> [6 May 2004].
- _____. 2004c. PM_{2.5} Inventory Resource Center. Available online: <<http://www.epa.gov/ttn/chief/eiip/pm25inventory/>> [6 May 2004].
- _____. 2004d. PM_{2.5} Designations. Available online: <<http://www.epa.gov/pmdesignations/index.htm>> [1 June 2004].
- _____. 2004e. *Air Quality Criteria for Particulate Matter*. EPA/600/P-99/002aF. Available online: <<http://cfpub2.epa.gov/ncea/cfm/partmatt.cfm>> [10 November 2004].
- Ferguson, S.A. 2001. Smoke dispersion prediction systems. Pages 163-176 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- Firewise. 1998. Wildland fire management terminology. *Wildfire News and Notes* 12(1, March). Available online: <<http://www.firewise.org/pubs/wnn/vol12/no1/index.html>> [20 October 2004].
- _____. 2004. Firewise glossary. Available online: <<http://www.firewise.org/glossary/fwglossary.pdf>> [21 May 2004].

- Fleming, J.R., and B.R. Knorr. 2004. History of the Clean Air Act. Available online: <<http://www.ametsoc.org/sloan/cleanair/index.html>> [25 February 2004].
- Graham, R.T., S. McCaffrey, and T.B. Jain, tech eds. 2004. *Science Basis for Changing Forest Structure to Modify Wildfire Behavior and Severity*. General Technical Report RMRS-GTR-120, Rocky Mountain Research Station, USDA Forest Service, Ogden, UT. Available online: <http://www.fs.fed.us/rm/pubs/rmrs_gtr120.pdf> [28 April 2004].
- Hardy, C.C., and B. Leenhouts. 2001. Introduction. Pages 3-7 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, S.M. Hermann, and R.E. Mutch. 2001a. The wildland fire imperative. Pages 11-19 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, _____, and _____. 2001b. The smoke management imperative. Pages 21-24 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. 2001c. *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- Hessburg, P.F., B.G. Smith, R.B. Slater, R.D. Ottmar, and E. Alvarado. 2000. Recent changes (1930s-1990s) in spatial patterns of interior northwest forests, USA. *Forest Ecology and Management* 136:53-83.
- Huff, M.H., R.D. Ottmar, E. Alvarado, R.E. Vihnanek, J.F. Lehmkuhl, P.F. Hessburg, and R.L. Everett. 1995. *Historical and Current Forest Landscapes in Eastern Oregon and Washington. Part II: Linking Vegetation Characteristics to Potential Fire Behavior and Related Smoke Production*. General Technical Report PNW-GTR-355, USDA Forest Service Pacific Northwest Research Station, Portland Oregon. Available online: <<http://www.fs.fed.us/pnw/pubs/gtr355/gtr355a.pdf>> [3 May 2004].
- IDEQ (Idaho Department of Environmental Quality). 2002. *Wildfire Natural Events Action Plan*. Available online: <<http://www.deq.state.id.us/air/smoke/NEAP/NEAP.pdf>> [22 January 2004].
- _____. 2004. Idaho Nonattainment Areas. Available online: <http://www.deq.state.id.us/air/monitoring/Idaho_Nonattainment_Areas.pdf> [20 October 2004].
- Jones & Stokes. 2004. *Nonburning Alternatives to Prescribed Fire on Wildlands in the Western United States*. Available online: <http://www.wrapair.org/forums/fejf/documents/altwild/Nonburning_Alternatives_Final_Report.pdf> [3 May 2004].
- Lindeburgh, S.B. 1990. *Effects of Prescribed Fire on Site Productivity: A Literature Review*. B.C. Ministry of Forestry, Victoria, BC, Canada.
- Martin, R.E. 1990. Goals, methods, and elements of prescribed burning. Pages 55-66 in *Natural and Prescribed Fire in Pacific Northwest Forests*, J.D. Walstad, S.R. Radosевич, and D.V. Sandberg, eds. Oregon State University Press, Corvallis, OR.
- Montana/Idaho Airshed Group. 2004. *Montana/Idaho Airshed Group Operating Guide*. Available online: <http://www.fs.fed.us/r1/fire/nrcc/Smoke_web_pages/OpGuide.pdf> [22 October 2004].
- National Wildfire Coordinating Group. 1996. *Glossary of Wildland Fire Terminology*. Available online: <<http://www.fire.blm.gov/training/standards/GLOSSARY.PDF>> [6 June 2004].

- _____. 2001. *Fire Effects Guide*. Available online: <<http://fire.r9.fws.gov/ifcc/monitor/FEG.pdf>> [28 April 2004].
- Neuenschwander, L.F., and R.N. Sampson. 2000. A wildfire and emissions policy model for the Boise National Forest. Pages 289-309 in *Mapping Wildfire Hazards and Risks*, R.N. Sampson, R.D. Atkinson, and J.W. Lewis, eds. Food Products Press, Binghamton, NY.
- Nichols, M.D. 1996. Memorandum dated May 30 to EPA Regional Directors. Subject: Areas Affected by PM₁₀ Natural Events. Available online: <<http://www.epa.gov/ttn/oarpg/t1/memoranda/nepol.pdf>> [10 May 2004].
- Norris, L.A. 1990. An overview and synthesis of knowledge concerning natural and prescribed fire in Pacific Northwest forests. Pages 7-22 in *Natural and Prescribed Fire in Pacific Northwest Forests*, J.D. Walstad, S.R. Radosevich, and D.V. Sandberg, eds. Oregon State University Press, Corvallis, OR.
- NRMC (Northwest Regional Modeling Consortium). 2004. The Northwest Regional Modeling Consortium. Available online: <<http://www.atmos.washington.edu/~cliff/consortium.html>> [7 May 2004].
- O'Laughlin, J., and P.S. Cook. 2003. Inventory-based forest health indicators: implications for national forest management. *Journal of Forestry* 101(2):11-17.
- Ottmar, R.D. 2001. Smoke source characteristics. Pages 89-105 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, and T.R. Reinhardt. 2001. Smoke exposure among fireline personnel. Pages 51-57 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, and D.V. Sandberg. 2001. Wildland fire in eastern Oregon and Washington. *Northwest Science* 75(Special Issue):46-54.
- _____, J.L. Peterson, B. Leenhouts, and J.E. Core. 2001. Smoke management: techniques to reduce or redistribute emissions. Pages 141-160 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, G.K. Anderson, P.J. DeHerrera, and T.E. Reinhardt. 2002. *Consume User's Guide, Version 2.1, Draft*. Available online: <http://www.fs.fed.us/pnw/fera/products/consume/CONSUME21_USER_GUIDE.DOC> [3 May 2004].
- Peterson, J.L. 2001. Regulations for smoke management. Pages 61-74 in *Smoke Management Guide for Prescribed and Wildland Fire, 2001 Edition*, C.C. Hardy, R.D. Ottmar, J.L. Peterson, J.E. Core, and P. Seamon, eds. National Wildfire Coordination Group, PMS 420-2. Available online: <<http://www.nwcg.gov/pms/pubs/SMG-72.pdf>> [10 December 2003].
- _____, and B. Leenhouts. 1997. What wildland fire conditions minimize emissions and hazardous air pollutants and can land management goals still be met? Draft paper prepared for the Wildland Fire Issues Group, U.S. Environmental Protection Agency, Washington, D.C. Available online: <<http://www.epa.gov/ttn/faca/pbdir/append-a.pdf>> [23 January 2004].
- Pyne, S.J. 1982. *Fire in America: A Cultural History of Wildland and Rural Fire*. Princeton University Press, Princeton, NJ.
- _____. 1984. *Introduction to Wildland Fire*. John Wiley & Sons, Inc., New York, NY.
- _____. 1997. *America's Fires: Management on Wildlands and Forests*. Forest History Society, Durham, NC.
- _____. 2001. *Year of the Fires: The Story of the Great Fires of 1910*. Viking Penguin Group, New York, NY.

- Radke, L.F., D.E. Ward, and P.J. Riggan. 2001. A prescription for controlling the air pollution resulting from the use of prescribed biomass fire: clouds. *International Journal of Wildland Fire* 10:103-111.
- Reinhardt, E.D., R.E. Keane, and J.K. Brown. 2001. Modeling fire effects. *International Journal of Wildland Fire* 10:373-380.
- Riebau, A.R., and D. Fox. 2001. The new smoke management. *International Journal of Wildland Fire* 10:415-427.
- Rogers, P., D. Atkins, M. Frank, and D. Parker. 2001. *Forest Health Monitoring in the Interior West: A Baseline Summary of Forest Issues, 1996-2000*. General Technical Report RMRS-GTR-75, USDA Forest Service, Rocky Mountain Research Station, Ogden, UT. Available online: <http://www.fs.fed.us/rm/pubs/rmrs_gtr75.pdf> [19 April 2004].
- Sandberg, D.V., R.D. Ottmar, J.L. Peterson, and J. Core. 2002. *Wildland Fire on Ecosystems: Effects of Fire on Air*. General Technical Report RMRS-GTR-42-vol. 5. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT. Available online: <http://www.fs.fed.us/rm/pubs/rmrs_gtr42_5.pdf> [30 January 2004].
- Shindler, B., and E. Toman. 2003. Fuel reduction strategies in forest communities: a longitudinal analysis of public support. *Journal of Forestry* 101(9):8-15.
- USDI (U.S. Department of Interior), U.S. Department of Agriculture, Department of Energy, Department of Defense, Department of Commerce, U.S. Environmental Protection Agency, Federal Emergency Management Service, and National Association of State Foresters. 2001. *Review and Update of the 1995 Federal Wildland Fire Management Policy*. Available online: <http://www.nifc.gov/fire_policy/index.htm> [35 March 2004].
- USFS (USDA Forest Service). 2003. Fire Effects Tradeoff Model (FETM). Available online: <<http://www.fs.fed.us/r6/aq/fetm/index.htm>> [25 October 2004].
- _____. 2004a. Hayman Fire & BAER Information: Wildland Fire Terminology. Available online: <<http://www.fs.fed.us/r2/psicc/hayres/terminology.htm>> [19 April 2004].
- _____. 2004b. AirFire Home Page. Available online: <<http://www.fs.fed.us/pnw/airfire>> [28 April 2004].
- _____. 2004c. FERA—Fire and Environmental Research Applications Team. Available online: <<http://www.fs.fed.us/pnw/fera>> [28 April 2004].
- _____. 2004d. Fire Consortia for Advanced Modeling of Meteorology and Smoke (FCAMMS). Available online: <<http://www.fs.fed.us/fcamms>> [7 May 2004].
- _____. 2004e. Wildland Fire Use. Available online: <http://www.fs.fed.us/fire/fireuse/wildland_fire_use/use_index.html> [20 October 2004].
- _____ and EPA. 2004. Blue Sky Rains—Overview. Available online: <<http://blueskyrains.org/pnw/>> [5 May 2004].
- Ward, D. 2001. Combustion chemistry and smoke. Pages 55-77 in *Forest Fires: Behavior and Ecological Effects*, E.A. Johnson and K. Miyanishi, eds. Academic Press, San Diego, CA.
- _____, and C.C. Hardy. 1991. Smoke emissions from wildland fires. *Environmental International* 17:117-134.
- _____, W.M. Hao, R.A. Susott, and R.J. Yokelson. 1994. Chemical characterization of smoke from wildland fires. Paper presented at Research and Applications of Chemical Sciences in Forestry, 1994, February 1-2, Starkville, MS.
- Wegman, L. 2004, March 31. Letter from EPA Director, Air Quality Strategies and Standards Division, to Ms. Sandra Ely, President, Western States Air Resources Council. Available online: <<http://www.westar.org/Docs/elyNEP.doc>> [18 October 2004].
- WESTAR (Western States Air Resources Council). 2003. *Evaluation of Resources Needed by State Air Quality Agencies to Develop Regional Haze Control Plans*. Available online: <<http://www.westar.org/Docs/SIPrptFinal.doc>> [10 May 2004].
- _____. 2004. About WESTAR. Available online: <<http://www.westar.org/whatis1.html>> [8 March 2004].

- WGA (Western Governors' Association, Air Quality Initiative Steering Committee). 1997. Improving the State Implementation Plan Process. Available online: <<http://www.westgov.org/wga/publicat/sippap3.htm>> [30 March 2004].
- White, S.M. 2004. *Bridging the worlds of fire managers and researchers: lessons and opportunities from the wildland fire workshops*. General Technical Report PNW-GTR-599, USDA Forest Service, Pacific Northwest Research Station, Portland, OR. Available online: <<http://www.fs.fed.us/pnw/pubs/gtr599.pdf>> [30 April 2004].
- WRAP (Western Regional Air Partnership). 2001a. *Policy for Categorizing Fire Emissions*. Available online: <<http://www.wrapair.org/forums/fejf/documents/nbtt/FirePolicy.pdf>> [5 February 2004].
- _____. 2001b. *Wildland Fire Elements of a Basic Smoke Management Program*. Available online: <http://www.wrapair.org/forums/fejf/documents/task2/BSMP_WF_dft.pdf> [5 February 2004].
- _____. 2002. *Western Regional Air Partnership Policy on Enhanced Smoke Management Programs for Visibility*. Available online: <http://www.wrapair.org/forums/fejf/documents/esmptt/policy/030155_ESMP_Policy.pdf> [5 February 2004].
- _____. 2003a. *WRAP Policy Fire Tracking Systems*. Available online: <<http://www.wrapair.org/forums/fejf/documents/fts/WRAPFTSPolicy.pdf>> [3 May 2004].
- _____. 2003b. *Facts about The WRAP*. Available online: <http://www.wrapair.org/forums/cc/projects/handouts/031109WRAP_Facts.pdf> [23 January 2004].
- _____. 2003c. Fire Emissions Joint Forum: Emission Reduction Techniques Joint Task Team. Available online: <<http://www.wrapair.org/forums/fejf/documents/ert/index.html>> [23 January 2004].
- Wright, H.A., and A.W. Bailey. 1982. *Fire Ecology*. John Wiley & Sons, Inc., New York, NY.

Personal Communications

- Edwards, M. Idaho Department of Environmental Quality, Boise. 3 March 2004.