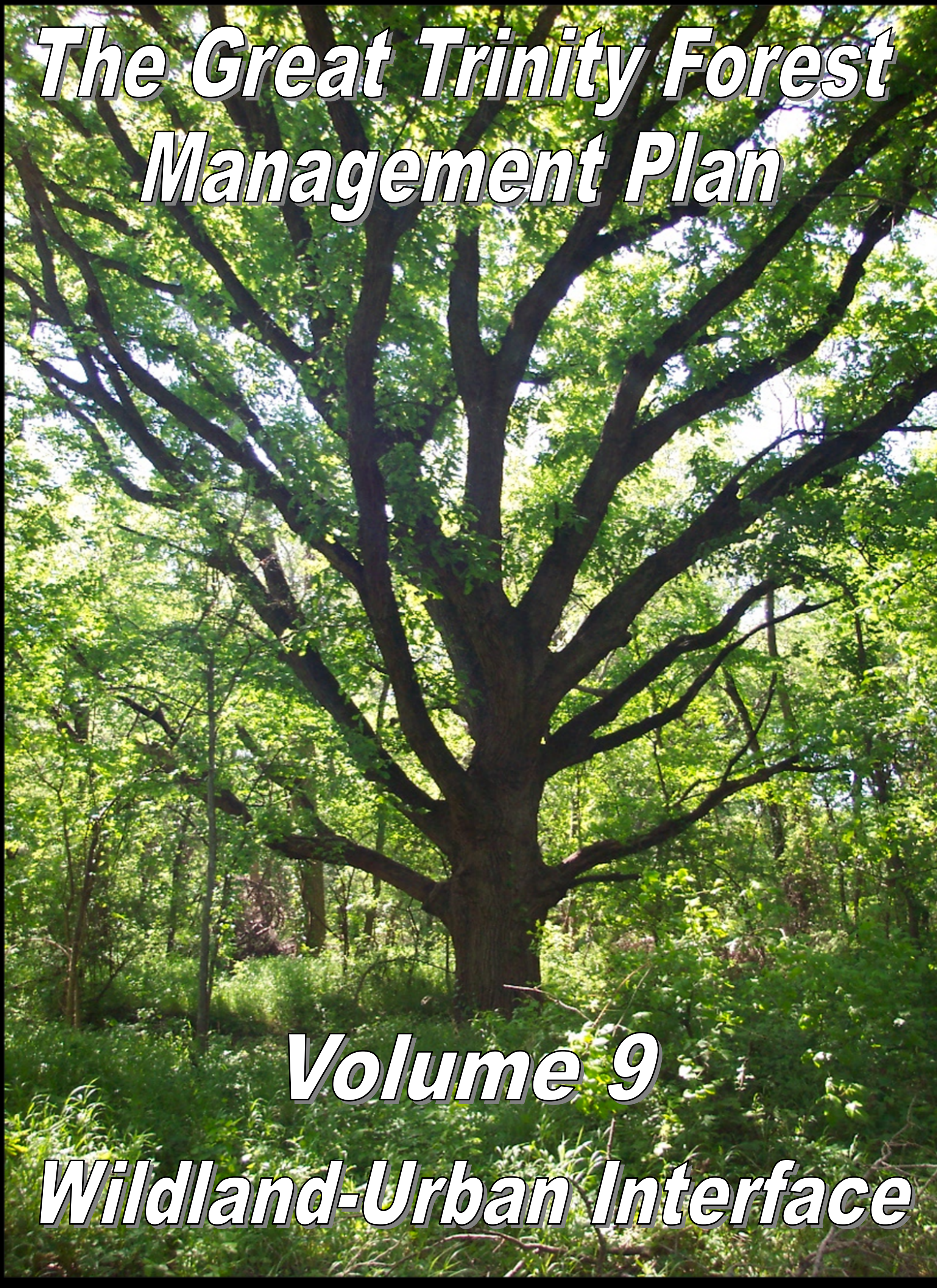
The Great Trinity Forest Management Plan



Volume 9

Wildland-Urban Interface

GREAT TRINITY FOREST

The Wildland-Urban Interface

Discussion of wildland fire and prescribed burning within the forest.

Volume 9

Table of Contents

DISCUSSION AND RECOMMENDATIONS

Discussion – Wildland Fire

The unique arrangement of the Great Trinity Forest (GTF) within the boundaries of the City of Dallas presents itself with many opportunities. With these opportunities, though, there are fundamental risks that should be acknowledged. The risk of wildland fire occurring within the GTF appears limited based on the current vegetation and reports of no past fire history within the forest (Personal communication with Dallas Fire-Rescue personnel). Despite this, it is important to consider the potential hazards posed to surrounding communities and the readiness of the agencies that would be tasked with managing such an occurrence.

The proposed management actions will have a variety of affects on the forest structure and fuel loading. Areas that will receive active management, namely herbicide application to the overstory followed by planting, will become more likely to carry a fire than the surrounding "Wilderness" forest type. Grassland or prairie areas could pose significant risk to surrounding communities, particularly the western boundary of the forest near the Joppy community. Management and development of the GTF will result in an increase in the number of visitors to the forest, thus leading to a higher potential for fire to occur. It should be noted that most wildfires occurring in Texas are a result of arson or the burning of debris.

Currently the Dallas Fire-Rescue Department (DFR) maintains 5 Type VI/ Brush truck units at various stations on the south side of Dallas. The department also does not have personnel particularly trained in wildland firefighting, i.e. "Red Card" Certified as wildland firefighters. Annually the department becomes involved with situations that could potentially escalate into wildland fire incidents, such as brush and grass fires, downed utility lines, vehicle fires, and arson.

Other available resources in the area include tractor/plow units staffed by Texas Forest Service personnel in Granbury, Greenville and McGregor. These regional offices also house regional fire coordinators and other individuals trained in wildland fire and incident management. Surrounding fire departments that work with the Dallas Fire-Rescue Department on a mutual aid basis do maintain units trained in wildland fire fighting and would be potential responders to fire incidents within the GTF. The National Guard in the area is trained to provide air support and helicopter bucket drops for wildland fire incidents and should be considered as potential resources.

In lieu of development along the Trinity Corridor, the DFR has prepared a budget that addresses the issues of medical and wildland incidents. Within the budget the DFR has outlined the need for a water tanker truck and also recommendations for outfitting the existing booster fleet with equipment appropriate for wildland incidents. The budget also mentions relocating resources to stations closer to the GTF and increasing the training of personnel in operating the Booster Pumpers, among other things.

Recommendations – Wildland Fire

It is recommended that the City of Dallas continue to work closely with surrounding agencies in regards to wildfire prevention and management. It is encouraged that the city work with local Texas Forest Service Regional Fire Coordinators and also Urban Wildland Interface (UWI) Coordinators to investigate the need for a Community Wildfire Protection Plan and explore wildland incident training opportunities for DFR personnel. In regards to the forest itself, areas should be identified by the forester as permanent protection breaks; such as the Spine Trails, highway, railroad, and utility right of ways, and also waterways. An effort should be made to bring to the attention of local residents the risk posed by wildfire and why it is important to create defensible space around valued structures.

Discussion – Prescribed Burning

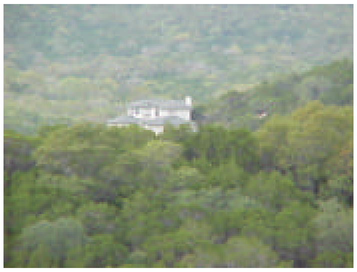
Prescribed burning is a useful tool for managing natural resources. It lends itself well to maintaining natural communities and reducing the difficulty of controlling wildfires. Within the GTF, though, prescribed burning should be applied with extreme caution due to the potential risks of fire escapes and adverse affects from smoke. Therefore, prescribed burning should be conducted only after thorough consideration and planning has been implemented. Burns should be goal specific and it is advised that other methods of vegetation management (i.e., discing, mowing, or herbicide application) be investigated before deciding to proceed with a prescribed burn. It is recommended that prescribed burns have the oversight of a Certified Burn Boss and be conducted by specially trained and equipped personnel.

Attached Information

The attached information is an overview of subjects related to the Urban Wildland Interface (UWI) and prescribed burning.

Great Trinity Forest - Emergency - Fire

Living in the Urban Wildland Interface



Over the past century, America's population has nearly tripled. Throughout the United States, much of the country's new growth encroaches on wildland areas, as cities and suburbia expand into what was once considered rural America. This continued encroachment brings people and structures into close proximity with large amounts of vegetation. The junction of homes with undeveloped areas of grass, brush and trees is known as the Urban Wildland Interface (UWI). Placement of structures within or adjacent to flammable vegetation renders them extremely vulnerable to wildfire. Should a wildland fire occur in an interface area, homes and other structures could simply be additional concentrated fuels for the wildfire to consume.

Seven different regions in Texas, each having some type of Urban Wildland Interface issue, have been delineated. The largest concentrations of high-risk UWI areas can be found in counties along the I-35 corridor from Dallas to San Antonio and along the I-10 corridor from San Antonio to Houston.

The wildfire disaster cycle begins when homes are built within urban/wildland interface areas. All too often, wildland fires have occurred before and will occur again in these areas. When wildfires do occur, they advance through all available fuels, which may well include homes and other structures. Even when homes are lost, though, many homeowners simply opt to build even larger homes in the same spot, because of the availability of low cost emergency/disaster loans. When homeowners rebuild homes without incorporation of wildfire mitigation measures, however, they unwittingly recreate the same conditions that led to the initial losses.

Wildland fires have destroyed more than 10,000 homes and 20,000 other structures and facilities since 1970. These wildfires cost government agencies some $20 billion in suppress costs and the insurance industry another $6 billion in restitution. More than 620 wildland firefighters have died in the line of duty since 1910.

UWI and fire personnel are working to make individuals and communities aware of the dangers associated with wildland fires so that the wildland fire disaster cycle can be stopped. Mitigation efforts by individual property owners represent great starts, but community-wide implementation of wildland fire safety measures remains the ultimate goal. Increased awareness and use of firewise practices will help save lives and property.

The Texas Forest Service (TFS), along with numerous other partners, has taken an active role in wildfire prevention and suppression. Agency employees are currently working with and continuing to identify communities that are at high risk for losses from wildfire. Through property owner and stakeholder meetings, the Texas Forest Service helps people become aware of wildland fire dangers and promotes the use of defensible (or survivable) space around homes. Meetings typically address hints to protect structures; firewise landscaping; the use of firewise building materials; property access by firefighting personnel and equipment; community involvement; and life safety measures. Find out more about Urban Wildland Interface issues and related topics at your local Texas Forest Service office or at the following Internet web links:

http://txforestservice.tamu.edu/
http://www.firewise.org/
http://www.ticc.fws.gov/
http://www.nfpa.org/
http://www.nwcg.gov/
http://www.usfa.fema.gov

Preparing a Community Wildfire Protection Plan

A Handbook for Wildland–Urban Interface Communities

Sponsored By:

Communities Committee • National Association of Counties • National Association of State Foresters
Society of American Foresters • Western Governors' Association

March 2004

Photo: CA Dept. of Forestry and Fire Protection

Introduction

The idea for community-based forest planning and prioritization is neither novel nor new. However, the incentive for communities to engage in comprehensive forest planning and prioritization was given new and unprecedented impetus with the enactment of the Healthy Forests Restoration Act (HFRA) in 2003.

This landmark legislation includes the first meaningful statutory incentives for the US Forest Service (USFS) and the Bureau of Land Management (BLM) to give consideration to the priorities of local communities as they develop and implement forest management and hazardous fuel reduction projects.

In order for a community to take full advantage of this new opportunity, it must first prepare a Community Wildfire Protection Plan (CWPP). Local wildfire protection plans can take a variety of forms, based on the needs of the people involved in their development. Community Wildfire Protection Plans may address issues such as wildfire response, hazard mitigation, community preparedness, or structure protection—or all of the above.

The process of developing a CWPP can help a community clarify and refine its priorities for the protection of life, property, and critical infrastructure in the wildland–urban interface. It also can lead community members through valuable discussions regarding management options and implications for the surrounding watershed.

The language in the HFRA provides maximum flexibility for communities to determine the substance and detail of their plans and the procedures they use to develop them. Because the legislation is general in nature, some communities may benefit from assistance on how to prepare such a plan.

This *Handbook* is intended to provide communities with a concise, step-by-step guide to use in developing a CWPP. It addresses, in a straightforward manner, issues such as who to involve in developing a plan, how to convene other interested parties, what elements to consider in assessing community risks and priorities, and how to develop a mitigation or protection plan to address those risks.

This guide is not a legal document, although the recommendations contained here carefully conform to both the spirit and the letter of the HFRA. The outline provided offers one of several possible approaches to planning. We hope it will prove useful in helping at-risk communities establish recommendations and priorities that protect their citizens, homes, and essential infrastructure and resources from the destruction of catastrophic wildfire.

Cover images

Photo: David McNew/Getty Images

Photo: Justin Sullivan/Getty Images

Discussion

Photo: State and Private Forestry, Cooperative Programs Pacific Northwest Region

Communities and the Wildland–Urban Interface

The wildland–urban interface (WUI) is commonly described as the zone where structures and other human development meet and intermingle with undeveloped wildland or vegetative fuels. This WUI zone poses tremendous risks to life, property, and infrastructure in associated communities and is one of the most dangerous and complicated situations firefighters face.

Both the National Fire Plan and the Ten-Year Comprehensive Strategy for Reducing Wildland Fire Risks to Communities and the Environment place a priority on working collaboratively within communities in the WUI to reduce their risk from large-scale wildfire.

The HFRA builds on existing efforts to restore healthy forest conditions near communities and essential community infrastructure by authorizing expedited environmental assessment, administrative appeals, and legal review for hazardous fuels projects on federal land.

The Act emphasizes the need for federal agencies to work collaboratively with communities in developing hazardous fuel reduction projects, and it places priority on treatment areas identified by communities themselves in a CWPP.

Role of Community Wildfire Protection Plans

The HFRA provides communities with a tremendous opportunity to influence where and how federal agencies implement fuel reduction projects on federal lands and how additional federal funds may be distributed for projects on nonfederal lands. A CWPP is the most effective way to take advantage of this opportunity.

Local wildfire protection plans can take a variety of forms, based on the needs of those involved in their development. They can be as simple or complex as a community desires.

The *minimum requirements* for a CWPP as described in the HFRA are:

(1) **Collaboration:** A CWPP must be collaboratively developed by local and state government representatives, in consultation with federal agencies and other interested parties.

(2) **Prioritized Fuel Reduction:** A CWPP must identify and prioritize areas for hazardous fuel reduction treatments and recommend the types and methods of treatment that will protect one or more at-risk communities and essential infrastructure.

(3) **Treatment of Structural Ignitability:** A CWPP must recommend measures that homeowners and communities can take to reduce the ignitability of structures throughout the area addressed by the plan.

The HFRA requires that three entities must mutually agree to the final contents of a CWPP:

- The applicable local government (i.e., counties or cities);
- The local fire department(s); and
- The state entity responsible for forest management.

In addition, these entities are directed to consult with and involve local representatives of the USFS and BLM and other interested parties or persons in the development of the plan. The process is intended to be open and collaborative, as described in the Ten-Year Strategy, involving local and state officials, federal land managers, and the broad range of interested stakeholders.

If a community already has a plan that meets these requirements, the community need not develop an additional plan for the purposes of the HFRA.

Benefits to Communities

In the context of the HFRA, a CWPP offers a variety of benefits to communities at risk from wildland fire. Among those benefits is the opportunity to establish a localized definition and boundary for the wildland–urban interface.

In the absence of a CWPP, the HFRA limits the WUI to within ½ mile of a community's boundary or within 1½ miles when mitigating circumstances exist, such as sustained steep slopes or geographic features aiding in creating a fire break. Fuels treatments can occur along evacuation routes regardless of their distance from the community. At least 50 percent of all funds appropriated for projects under the HFRA must be used within the WUI as defined by either a CWPP or by the limited definition provided in the HFRA when no CWPP exists.[1]

In addition to giving communities the flexibility to define their own WUI, the HFRA also gives priority to projects and treatment areas identified in a CWPP by directing federal agencies to give specific consideration to fuel reduction projects that implement those plans. If a federal agency proposes a fuel treatment project in an area addressed by a community plan but identifies a different treatment method, the agency must also evaluate the community's recommendation as part of the project's environmental assessment process.

Preparing a Community Wildfire Protection Plan

- These step-by-step recommendations are intended to help communities develop a wildfire protection plan that addresses the core elements of community protection. Items required under the HFRA are addressed, as are some additional issues that often are incorporated into wildfire protection planning. Actions beyond those listed in the legislation are not required for the purposes of the HFRA.

- Community fire planning need not be a complex process. A community can use this outline to develop a fire plan that is as extensive or as basic as is appropriate and desired by the community.

- A key element in community fire planning should be the meaningful discussion it promotes among community members regarding their priorities for local fire protection and forest management. This handbook should help to facilitate these local discussions.

[1] In the absence of a CWPP, Section 101 (16) of the HFRA defines the wildland–urban interface as " (i) an area extending ½ mile from the boundary of an at-risk community; (ii) an area within 1½ miles of the boundary of an at-risk community, including any land that (I) has a sustained steep slope that creates the potential for wildfire behavior endangering the at-risk community; (II) has a geographic feature that aids in creating an effective fire break, such as a road or ridge top; or (III) is in condition class 3, as documented by the Secretary in the project-specific environmental analysis; (iii) an area that is adjacent to an evacuation route for an at-risk community that the Secretary determines, in cooperation with the at-risk community, requires hazardous fuels reduction to provide safer evacuation form the at-risk community."

✔ STEP ONE: Convene Decisionmakers

The initial step in developing a CWPP should be formation of an operating group with representation from local government, local fire authorities, and the state agency responsible for forest management.

Together, these three entities form the core decision-making team responsible for the development of a CWPP as described in the HFRA. The core team members must mutually agree on the plan's final contents.

In communities where several local governments and fire departments are within the planning area, each level of government/authority may need to convene ahead of time and identify a single representative to participate, on its behalf, as a core team member.

✔ STEP TWO: Involve Federal Agencies[2]

Once convened, members of the core team should engage local representatives of the USFS and BLM to begin sharing perspectives, priorities, and other information relevant to the planning process.[3]

Because of their on-the-ground experience, mapping capabilities, and knowledge of natural resource planning, these local land management professionals will be key partners for the core team. In some landscapes, they will also be largely responsible for implementing the priorities established in the resulting CWPP.

✔ STEP THREE: Engage Interested Parties

The success of a CWPP also hinges on the ability of the core team to effectively involve a broad range of local stakeholders, particularly when the landscape includes active and organized neighborhood associations, community forestry organizations that work in forest management, and other stakeholder groups that display a commitment to fire protection and fuels management.

Substantive input from a diversity of interests will ensure that the final document reflects the highest priorities of the community. It will also help to facilitate timely implementation of recommended projects. In some circumstances, the core team may wish to invite local community leaders or stakeholder representatives to work along with them in final decisionmaking.

As early as possible, core team members should contact and seek active involvement from key stakeholders and constituencies such as:

- Existing collaborative forest management groups
- City Council members
- Resource Advisory Committees
- Homeowners Associations—particularly those representing subdivisions in the WUI
- Division of Wildlife/Fish and Game—to identify locally significant habitats
- Department of Transportation—to identify key escape corridors
- Local and/or state emergency management agencies
- Water districts—to identify key water infrastructure
- Utilities
- Recreation organizations
- Environmental organizations
- Forest products interests
- Local Chambers of Commerce
- Watershed councils

This list provides a starting point and is by no means exhaustive.

[2] Sec. 103 (b)(2) of the Act states that "the Federal Advisory Committee Act (5 U.S.C. App.) shall not apply to the planning process and recommendations concerning community wildfire protection plans."

[3] A CWPP is legally applicable to federal lands only if they are managed by the USFS or the BLM. Nothing in the Act requires a community to exclude other federal agencies—such as the Fish and Wildlife Service or the National Park Service—from planning efforts, but those agencies are not bound by the provisions of the HFRA.

Photo: New Mexico State Forestry

In addition to directly contacting key individuals and organizations, core team members may want to consider using a public notice or public meeting process to acquire additional, more generalized input as the plan is developed.

✔ STEP FOUR: Establish a Community Base Map

Using available technology and local expertise, the core team and key partners should develop a base map of the community and adjacent landscapes of interest. This map will provide a visual information baseline from which community members can assess and make recommendations regarding protection and risk-reduction priorities.

To the extent practicable, the map should identify:

- Inhabited areas at potential risk to wildland fire;
- Areas containing critical human infrastructure—such as escape routes, municipal water supply structures, and major power or communication lines—that are at risk from fire disturbance events; and
- A preliminary designation of the community's WUI zone.

✔ STEP FIVE: Develop a Community Risk Assessment

The development of a community risk assessment will help the core team and community members more effectively prioritize areas for treatment and identify the highest priority uses for available financial and human resources.

A meaningful community assessment can be developed by considering the risk factors identified below. Choose an appropriate adjective rating (such as high, medium, and low) that best represents the risk to the community posed by each factor. Display the results on the base map to develop a useful tool for the final decision-making process.

State and federal land managers will be a valuable resource in helping communities locate the best available data and in producing quality maps that display and aid assessment of that data. Engaging key stakeholders in the rating process will be essential to a successful outcome.

A. Fuel Hazards

To the extent practicable, evaluate the vegetative fuels on federal and nonfederal land within or near the community. Identify specific areas where the condition of vegetative fuels is such that, if ignited, they would pose a significant threat to the community or essential community infrastructure. Consider how the local topography (such as slope, aspect, and elevation) may affect potential fire behavior.

Identify areas affected by windthrow, ice storms, or insect and disease epidemics where fuels treatment would reduce wildfire risks to communities and/or their essential infrastructure.

State and federal resource planning documents can be a valuable source of information on local forest and rangeland conditions.

Rate each area of identified hazardous fuels and show each on the base map as a high, medium, or low threat to the community.

B. Risk of Wildfire Occurrence

Using historical data and local knowledge, determine the common causes and relative frequency of wildfires in the vicinity of the community. Consider the range of factors, including critical weather patterns, that may contribute to the probability of fire ignitions and/or extreme fire behavior.

Use relative ratings such as high, medium, and low to show areas of concern for fire starts on the base map.

C. Homes, Businesses, and Essential Infrastructure at Risk

Assess the vulnerability of structures within the community to ignition from firebrands, radiation, and convection. Document areas of concern.

Identify specific human improvements within or adjacent to the community, such as homes, businesses, and essential infrastructure (e.g., escape routes, municipal water supply structures, and major power and communication lines) that would be adversely impacted by wildfire.

Categorize all identified areas needing protection using ratings of high, medium, or low, and show them on the base map.

D. Other Community Values at Risk

At the community's option, the risk assessment may also consider other areas of community importance, such as critical wildlife habitat; significant recreation and scenic areas; and landscapes of historical, economic, or cultural value that would benefit from treatment to reduce wildfire risks. Additional recommendations from local stakeholders should be incorporated as appropriate.

Categorize all identified areas that warrant protection using the ratings of high, medium, or low, and show them on the base map.

E. Local Preparedness and Firefighting Capability

Assess the level of the community's emergency preparedness, including evacuation planning, safety zones, and fire assistance agreements, as well as the response capability of community and cooperator fire protection forces. Consider the insurance industry ISO rating, if available and applicable. Use the knowledge and experience of local officials to identify areas in need of improvement.

Incorporate local preparedness information into the base map as appropriate.

✔ STEP SIX: Establish Community Hazard Reduction Priorities and Recommendations to Reduce Structural Ignitability

Once the community assessment and base map are completed, the core team should convene all interested parties to discuss the results and their implications for local protection and hazard mitigation needs. A key objective of these discussions is to develop the community's prioritized recommendations for fuel treatment projects on federal and nonfederal lands in the WUI, along with the preferred treatment methods for those projects.

Recommendations should also be developed regarding actions that individuals and the community can take to reduce the ignitability of homes and other structures in the community's WUI zone.

While local interests are gathered, communities may also want to take this opportunity to identify and develop strategies to improve their emergency preparedness and fire response capability.

The discussion and identification of community priorities should be as open and collaborative as possible. Diverse community involvement at this stage is critical to the ultimate success of the CWPP.

Recommendations included in the final CWPP should clearly indicate whether priority projects primarily serve to protect the community and its essential infrastructure or are geared toward reducing risks to the other community values. Under the provisions of the HFRA, only projects that primarily serve to protect communities and essential infrastructure are eligible for the minimum 50 percent WUI funding specified in the legislation.

✔ **STEP SEVEN: Develop an Action Plan and Assessment Strategy**

Before finalizing the CWPP, core team members and key community partners should consider developing an action plan that identifies roles and responsibilities, funding needs, and timetables for carrying out the highest priority projects.

Additional consideration should be given to establishing an assessment strategy for the CWPP to ensure that the document maintains its relevance and effectiveness over the long term.[4]

✔ **STEP EIGHT: Finalize the Community Wildfire Protection Plan**[5]

The final step in developing a CWPP is for the core team to reconvene and mutually agree on the fuels treatment priorities, preferred methods for fuels treatment projects, the location of the wildland-urban interface, structural ignitability recommendations, and other information and actions to be contained in the final document.

If an associated action plan has not been developed, the core team should identify a strategy for communicating the results of the planning process to community members and key land management partners in a timely manner.

[4] Community planning participants may also want to participate in multiparty monitoring of USFS and BLM projects developed under the HFRA as provided for in Sec.102 (g)(5) of the legislation: "In an area where significant interest is expressed in multiparty monitoring, the Secretary shall establish a multiparty monitoring, evaluation, and accountability process in order to assess the positive or negative ecological and social effects of authorized hazardous fuels reductions projects."

[5] Some states have statutes that may require an environmental analysis for plans adopted by local or state agencies. In such states, core team members should determine whether formal environmental analysis is required before finalizing their plans.

Summary and Checklist

✔ **Step One: Convene Decisionmakers**

- Form a core team made up of representatives from the appropriate local governments, local fire authority, and state agency responsible for forest management.

✔ **Step Two: Involve Federal Agencies**

- Identify and engage local representatives of the USFS and BLM.
- Contact and involve other land management agencies as appropriate.

✔ **Step Three: Engage Interested Parties**

- Contact and encourage active involvement in plan development from a broad range of interested organizations and stakeholders.

✔ **Step Four: Establish a Community Base Map**

- Work with partners to establish a baseline map of the community that defines the community's WUI and displays inhabited areas at risk, forested areas that contain critical human infrastructure, and forest areas at risk for large-scale fire disturbance.

✔ **Step Five: Develop a Community Risk Assessment**

- Work with partners to develop a community risk assessment that considers fuel hazards; risk of wildfire occurrence; homes, businesses, and essential infrastructure at risk; other community values at risk; and local preparedness capability.
- Rate the level of risk for each factor and incorporate into the base map as appropriate.

✔ **Step Six: Establish Community Priorities and Recommendations**

- Use the base map and community risk assessment to facilitate a collaborative community discussion that leads to the identification of local priorities for fuel treatment, reducing structural ignitability, and other issues of interest, such as improving fire response capability.
- Clearly indicate whether priority projects are directly related to protection of communities and essential infrastructure or to reducing wildfire risks to other community values.

✔ **Step Seven: Develop an Action Plan and Assessment Strategy**

- Consider developing a detailed implementation strategy to accompany the CWPP, as well as a monitoring plan that will ensure its long-term success.

✔ **Step Eight: Finalize Community Wildfire Protection Plan**

- Finalize the CWPP and communicate the results to community and key partners.

Sponsor Organizations

Communities Committee of the Seventh American Forest Congress
www.communitiescommittee.org
919 Elk Park Rd.
Columbia Falls, MT 59912
Phone: (406) 892-8155
Fax: (406) 892-8161

National Association of Counties
www.naco.org
440 First Street, NW
Washington, DC 20001
Phone: (202) 393-6226
Fax: (202) 393-2630

National Association of State Foresters
www.stateforesters.org
444 N. Capitol St., NW Suite 540
Washington, DC 20001
Phone: (202) 624-5415
Fax: (202) 624-5407

Society of American Foresters
www.safnet.org
5400 Grosvenor Lane
Bethesda, MD 20814-2198
Phone: (301) 897-8720
Fax: (301) 897-3690

Western Governors' Association
www.westgov.org
1515 Cleveland Place
Suite 200
Denver, CO 80202-5114
Phone: (303) 623-9378
Fax: (303) 534-7309

For an electronic version of this Handbook and the latest information visit:
www.safnet.org/policyandpress/cwpp.cfm

Additional Resources on the Web:

- Federal Agency Implementation Guidance for the Healthy Forest Initiative and the Healthy Forest Restoration Act: www.fs.fed.us/projects/hfi/field-guide/
- Field Guidance for Identifying and Prioritizing Communities at Risk: www.stateforesters.org/reports/COMMUNITIESATRISKFG.pdf
- The National Fire Plan: www.fireplan.gov
- Fire Safe Councils: www.firesafecouncil.org
- Western Governors Association: www.westgov.org
- Collaboration:
  www.redlodgeclearinghouse.org
  www.snre.umich.edu/emi/lessons/index.htm

Examples of Community Fire Plans

(Note: these plans may not meet the requirements of HFRA, because they were created prior to its enactment)

Josephine County, Oregon: www.co.josephine.or.us/wildfire/index.htm

Applegate Fire Plan: www.grayback.com/applegate-valley/fireplan/index.asp

Colorado Springs, CO: csfd.springsgov.com/wildfiremitigation.pdf

Jefferson County, Colorado: www.co.jefferson.co.us/ext/dpt/admin_svcs/emergmgmt/index.htm

Lower Mattole Fire Plan: www.mattole.org/html/publications_publication_2.html

Trinity County Fire Management Plan: users.snowcrest.net/tcrcd/

Want to help protect your community from wildfire risk?

Check out this *NEW* Handbook for preparing community wildfire protection plans!

Communities Committee

NACO National Association of Counties

National Association of State Foresters Founded 1920

Society of American Foresters

Western Governors' Association

Society of American Foresters
5400 Grosvenor Lane
Bethesda, Maryland 20814-2198
www.safnet.org

A Guidance Document for Developing

Community Wildfire Protection Plans

TEXAS FOREST SERVICE
The Texas A&M University System

A collaborative approach to help protect life, property and natural resources through community-based planning

Overview

Wildfires are nothing new to the state of Texas. They are a part of our natural history and have shaped many of our native Texas ecosystems. What is new is the unprecedented growth and development that is occurring in locations across the state that were once rural. It is in this area where development meets native vegetation that the greatest risk to public safety and property from wildfire exists.

The **Urban Wildland Interface (UWI)** is most commonly described as a zone where human developments and improvements meet and intermix with wildland fuels. The intermingling of homes and wildland fuels is a volatile mix that under the right conditions can have catastrophic results.

The good news is many of the risks associated with living in wildland areas can be mitigated. The solutions to these problems should originate from the communities at risk, not just state and federal agencies. Texas is unique in that ninety-seven percent of land is privately owned, and most Texans would not have it any other way. Along with ownership comes the shared responsibility of all members of the community to take steps to reduce the risks associated with wildfires. One of the best strategies for reducing that risk is the development of a **Community Wildfire Protection Plan (CWPP)**.

This guide and associated CWPP template are intended to give communities a framework for developing a Community Wildfire Protection Plan that complies with the **Healthy Forest Restoration Act (HFRA)**. This template is just one example of the many approaches that communities can take when developing a CWPP. There are several guides and templates listed in the appendix section of this document.

The most important factor to take into consideration is that the CWPP is developed in a collaborative context.

What is a Community Wildfire Protection Plan?

- A CWPP is a written document, mutually agreed upon by local, state and federal representatives and stakeholders that identifies how a community will reduce its risks from wildland fire.
- Community Wildfire Protection Plans are authorized and defined in Title I of the Healthy Forest Restoration Act (HFRA), which was passed by Congress on November 21, 2003, and signed into law on December 3, 2003.
- The HFRA established unprecedented incentives for communities to take the lead role in community wildfire protection planning.

Why have a CWPP?

- The HFRA gives communities the opportunity to define their respective Urban Wildland Interface boundaries. Fifty percent of federal funds for fuels reduction must be spent in these areas.
- A CWPP gives communities an opportunity to influence the treatments used to reduce wildland fuels and restore ecosystem health.
- Communities that develop a CWPP are given priority when funding opportunities for fuels reduction on private and public lands are available.
- A CWPP determines strategies for reducing the risk wildfires pose to communities, critical watersheds and natural resources.

When should a CWPP be developed?

If the answer is yes to any of the following questions, then the county and/or community should consider developing a CWPP.

- Is the county/community in proximity to wildland fuels?
- Is the county/community listed as an “at-risk” community in the Federal Register or State Risk Assessment?
- Is the county/community in or adjacent to federal lands?

What are the minimum requirements for a CWPP?

- ***Prioritized Fuels Reduction*** - Identify and prioritize wildland areas for hazardous fuels reduction treatments, as well as recommending methods for achieving hazardous fuels reductions on both private and public lands.
- ***Treatment of Structural Ignitability*** – The CWPP must recommend measures for reducing structural ignitability throughout the at-risk community.
- ***Collaboration*** - The most important aspect of developing a CWPP is that the process used in achieving the first two objectives is a collaborative effort.

Who needs to be part of the planning process?

- Community wildfire protection planning should be spearheaded by local interests with support from state and federal agencies and non-governmental stakeholders.
- The HFRA requires that the local government, local fire authority and a state forestry representative mutually agree to the contents and actions recommended in the CWPP.
- Federal land managers should be included in the development process whenever planning areas are adjacent to federal lands. Their technical expertise can be extremely valuable to the CWPP development process.

From where do the guidelines for developing a CWPP come?

- Healthy Forest Restoration Act of 2003 (P.L. 108-148)
- *Preparing a Community Wildfire Protection Plan: A Handbook for Wildland-Urban Interface Communities* (Communities Committee, Society of American Foresters, National Association of Counties, National Association of State Foresters 2004) (*Foresters' Handbook*)
- *The Healthy Forests Initiative and Healthy Forests Restoration Act Interim Field Guide* (USDA Forest Service and Bureau of Land Management 2004) (*Field Guide*)
- Healthy Forests Initiative, 2002

[1] *Excerpt from Healthy Forests Restoration Act – HR 1904.* The term 'community wildfire protection plan means a plan for an at-risk community that

1. Is developed within the context of the collaborative agreements and the guidance established by the Wildland Fire Leadership Council and agreed to by the applicable local government, local fire department, and State Agency responsible for forest management, in consultation with interested parties and the Federal land management agencies managing land in the vicinity of the at-risk community.

2. Identifies and prioritizes areas for hazardous fuel reduction treatments and recommends the types and methods of treatment on Federal and non-Federal land that will protect one or more at-risk communities and essential infrastructure.

3. Recommends measures to reduce structural ignitability throughout the at-risk community.

How to use the CWPP Template

The template that accompanies this guidance document is intended to provide a process in which a CWPP can be developed that meets all of the requirements of Title I of the Healthy Forest Restoration act of 2003. It is organized into sections that break down the development of a CWPP step by step. The main categories are discussed individually, and instructions are provided in the template portion of the guide. There is no requirement to fill out all the boxes of the template. Keep in mind that the community wildfire protection planning and development process does not have to be overly complex. As long as it addresses the requirements outline in the following excerpt then your plan will be a success.

Section Overview

Section 1.0- Introduction

- Outlines who the core decision-making team will be for the plan and addresses the overall objective the plan will accomplish.

Section 2.0- Community Profile

- Provides a physical description of the community and its current wildfire response capabilities.

Section 3.0- Community Risk Assessment

- This section includes various components to consider when determining the risk wildfire poses to a community's assets. This portion of the plan helps establish an objective wildfire hazard rating for the communities in the planning area. A link to the community risk assessment rating form is included in the appendix section of this guide.

Section 4.0- Community Prescription/Mitigation Plan

- The community prescription and mitigation portion of this plan includes the specific goals of the plan, strategies for achieving those goals and individuals that can assist in attaining project objectives.

Section 5.0- Implementation Time Table/Monitoring

- This portion of the template assists communities with tracking and monitoring progress and accomplishments.

Section 6.0 - Declaration of Agreement and Concurrence

- This signature sheet indicates that the members of the planning team agree with the plan's contents and are prepared to move forward with implementing the plan.

Table of Contents

4.0 Community Prescription
- **4.1 Hazardous Fuels Reduction Project(s)**
- **4.2 Treatment of Structural Ignitability**
- **4.3 Public Outreach and Education**
- **4.4 Emergency Facilities/Equipment Enhancement**
- **4.5 Emergency Response Plan/Evacuation Plan/Wildfire Response Plan**
- **4.6 Evaluation of Restrictive Covenants and Ordinances**
- **4.7 Enhancement of Utilities and Infrastructure**
- **4.8 Evaluate, Update and Maintain Planning Commitments**
- **4.9 Develop/Review/Revise Memorandum of Understanding (MOU)**
- **4.10 Biomass/Utilization**

5.0 Implementation Timetable
- **5.1 Media Release(s)**
- **5.2 Tracking of Progress/Fire Planning Checklist**

6.0 Declaration of Agreement and Concurrence

7.0 Appendices

1.0 Introduction

Give a brief overview of what the community would like to accomplish in the process of developing and implementing a Community Wildfire Protection Plan.

1.1 Collaboration

It is a good Idea to indicate in the beginning of the document that the intent of the planning team is to be open and collaborative in its effort to improve the safety of the community and its resources. Below is an example of an opening statement that shows collaboration is a driving force behind the plans development.

This Community Wildfire Protection Plan is a collaborative effort between the following entities. The representatives listed below comprise the core decision-making team responsible for this report and mutually agree on the plan's contents.

Community Representative(s):
This would most likely be someone from local government, Emergency Management Coordinator, elected official or concerned citizen

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Local Fire Department Representatives:
(Local Fire Chief, member of FD, or the Fire Marshal)

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Texas Forest Service UWI Representatives:

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Federal Agency Representative:
(United States Forest Service Fire Management Officer, District Ranger or designee; United States Fish and Wildlife Service; National Parks Service; Board of Indian Affairs; Department of Energy; or Department of Defense.)

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

1.2 Statement of Intent

This is the overall intent of the plan.
Example:
The purpose of this plan is to position fire protection agencies, county/community leaders and natural resource professionals to be better prepared to protect the community's residents and natural resources from the negative impacts of wildfire.

1.3 Historical Fire Occurrence

This section can be emphasized with maps of historical fire occurrences, fire managers can provide you with this info.
Example:
The county has experienced several large wildfires over the last decade. These fires have threatened or damaged homes and valuable natural resources.

1.4 Existing Situation/Current Risks

Discuss how current conditions such as drought, mortality to trees and vegetation due to insect infestation or overcrowding have resulted in an increased risk to the community from wildfire.

Example:
Many individual homes and subdivisions have been built in areas that are prone to experiencing wildfires. Some developments lack fire hydrants or waters sources for fire service to utilize. In addition, the county is currently experiencing a long term drought that has increased the probability of extreme fire behavior.

1.5 Goals and Objectives

This section covers specific goals that you plan to accomplish.

Example:
Improve fire suppression and prevention capabilities
Determine appropriate hazardous fuels reduction projects
Restore ecosystem health
Promote measures to reduce structural ignition potential
Encourage economic development in the community through utilization

1.6 Planning Process

It is important to the success of the plan that the processes for developing the plan are considered beforehand.
For an example of a checklist see the CWPP Summary and checklist located in the appendices

2.0 Community Profile

This section can be a combination of a written description supported by maps which highlight areas that need attention in community wildfire planning and mitigation. A community is defined in the HFRA as a group of homes that share basic infrastructure.

2.1 Community Location

County	***Plans can be completed at the watershed, county or community level.***
Latitude/Longitude	***This section is for individual communities; plans at county level can list the communities at risk within the county.***
Plan Area and Unit Boundaries	***This section is very important. It allows for delineation of where the UWI exists in your community. If this step is skipped, a default boundary will be assigned.***
Frontage and/or Perimeter Road(s)	***This section gives an opportunity to reference the location if the area is not an incorporated community.*** **Example:** **The community is located in Lonestar county at the intersection of hwy 220 and FM 1398 .**
Additional Landmarks	

2.2 Community Size

This information can be obtained through the local county tax assessors.

Acreage	***Smaller communities can use acreage to determine size of communities.***					
Square Miles	***Counties would most likely use square miles as a reference to size.***					
Number of Lots	TOTAL		Developed		Undeveloped	

2.3 Structures

Depending on the size of the planning area, an estimated number will suffice.

Type	***Number or Percentage***
Homes	***Estimated number of site built homes.***
Mobile Homes	***Estimated number of manufactured homes.***
Outbuildings	***This field would be storage buildings, shops, barns and structures of that nature.***
Commercial Buildings	***Estimated number and potential types of commercial buildings.***
Other Structures	

2.4 Population

Total Population: ____________
Full Time Residents:__________%
Part Time Residents:__________%

2.5 Community Legal Structure

In this section list the government bodies within the planning area and a point of contact i.e. county, cities, towns and homeowners associations.

Organization	**Contact, Title**	**Phone Numbers**	**Email Address**

2.6 Utilities

Describe and discuss the various utilities in the area. I.e., are the power lines above ground or below ground? Are there any drilling rigs, gas pipelines or storage facilities in the area? Size and condition of water mains? Location and type of hydrants?

2.7 Emergency Response Capabilities

List the l*ocal, state and federal fire resources, their respective response times and what their capabilities are.*

Local	***Department Name Address***	***Contact Name Title Email***	***Phone Numbers***

Resources	**Response Time**	

Engines Type / ID / Capacity	**Dozers & Tractor Plows Type / ID /**	**Misc. (Tankers/Tenders, etc.) / Capacity**	**Aviation Type / ID / Capacity**

State	***Department Name Address***	***Contact Name Title Email***	***Phone Numbers***

Resources	**Response Time**	

Engines Type / ID / Capacity	**Dozers & Tractor Plows Type / ID /**	**Misc. (Tankers/Tenders, etc.) / Capacity**	**Aviation Type / ID / Capacity**

Federal	*Department Name Address*	*Contact Name Title Email*	*Phone Numbers*

Resources	**Response Time**	

Engines Type / ID / Capacity	**Dozers & Tractor Plows Type / ID /**	**Misc. (Tankers/Tenders, etc.) / Capacity**	**Aviation Type / ID / Capacity**

2.8 Schools

Discuss local schools, their proximity to wildland fuels and potential mitigation needs. Determine if sheltering potential exists and how these facilities will be affected in a wildfire. It is often the case that the safest place to be during a wildfire event is inside a structure, therefore evacuation may not be the safest alternative.

2.9 Emergency Medical Facilities

Discussions of local medical facilities, proximity to wildland fuels, potential mitigation needs and activities. Discuss any sheltering potential and how these facilities could be incorporated for educational outreach, etc.

2.10 Regulative Issues

Discuss local restrictions that need consideration when addressing fuels reduction projects and measures to reduce structural ignitability.

3.0 Community Risk Assessment

It is very important to establish what the risk level is for communities within the planning area. This allows efforts to be focused on the areas most at risk from wildfire and prioritization of your mitigation actives.

3.1 Access

Discuss the ability of fire services to respond to the community and the ability of residents to leave the community if evacuation is necessary. The county or city Emergency Management Coordinator will have an evacuation plan on file. Evaluate the load capacity of bridges, the width of community gates if present and the turnaround needs of emergency response vehicles. Pay special attention to areas with only one way to exit the community. Roads need to be wide enough for fire personnel to respond and residents to evacuate.

3.2 Topography

Topography increases the intensity of fire behavior and reduces a fire department's ability to respond in some cases. Focus special attention on areas with steep topography, especially if they border or are adjacent to escape routes.

3.3 Fuels

In this section, evaluate the fire regime and condition class of vegetation in the planning area. Fire regime is classified by the departure from historical fire occurrence. Examine how often the area burned historically, what types of fuels are present now and how a fire would behave under current conditions.

3.4 Construction

What exterior construction materials are predominately used in the community? Are they flammable or fire resistant? What percent of homes are vulnerable to ignition from firebrands or direct flame contact?

3.5 Water Sources

Identify existing water sources and potential water sources. This can be accomplished through the use of GIS-based maps or aerial photography. Texas Forest Service has completed profiles for East Texas counties that identify the locations of dry hydrants and drafting sources. Local fire departments will also be able to provide this information.

3.6 Expected Fire Behavior

Given the existing fuel, evaluate fire behavior in the planning area under both normal and extreme fire condition. Compare how a fire would behave after fuels modifications.

3.7 Community Hazard Rating

Low / Medium / High/Extreme
Based on the assessment of risk, assign an overall hazard rating for the community. Local fire services and Texas Forest Service will be able to assist you in determining the community risk rating. A risk assessment form will be included in the appendices of this document.

3.8 Assets at Risk

This section includes community assets such as schools, hospitals, economic centers, recreation areas and watersheds, etc., which can all be threatened by a wildfire. Compare the fuels reduction recommendations with habitat needs. They may be compatible or need consideration. With plants and animals, specify if they are listed on the Threatened & Endangered Species register and what is their status. Consider rating these assets with a priority of high, medium or low.

3.8.1 Natural Resources

Your local Texas Forest Service official, or local natural resource management agency representative, i.e. USDA Agriculture Extension Agent, Unite States Fish and Wildlife Service representative, Texas Parks and Wildlife Department representative, etc., can assist you with this section. When threatened and or endangered species are present within a fuels treatment area, consult with USFWS.

PLANT Name (Common/Scientific)	T & E Status	Priority
Discussion:		

ANIMAL Name (Common/Scientific)	T & E Status	Priority
Discussion:		

Watershed/Wetland Considerations	Priority
Discussion:	

3.8.2 <u>Commercial & Industrial Resources</u>

List and discuss any industrial sites that are essential to the community or that could pose a risk if threatened or damaged by wildfire.

Resource	Priority
Example	
Oil refineries	
Chemical plants	
Discussion:	

3.8.3 <u>Community Values & Cultural Assets</u>

List and discuss any community values and cultural assets i.e., historical sites, local parks, etc. that need consideration when implementing mitigation or suppression activities.

Resource	Priority
Example	
Historic buildings	
Historically significant or pre-Columbian sites	
Discussion:	

3.8.4 <u>Estimated Values at Risk</u>

Provide an approximate value for residential and commercial properties in the planning area.

Resource	Estimated value
Commercial	$
Residential	$
Natural	$
Discussion:	

4.0 Community Prescription/Mitigation Plan

In this portion of the plan a community has the opportunity to determine what mitigation activities are appropriate for that community. This is an excellent point to conduct public meetings that provide an opportunity for feedback.

4.1 Hazardous Fuels Reduction Projects

List specific priorities for hazardous fuels reduction and forest restoration. It would be beneficial to determine the types of fuels reduction treatments that are acceptable to the community before this stage of planning. Public input is very important at this point in the CWPP process.
Example:
Implement hazardous fuels reduction to remove vegetation and small diameter trees on 280 acres of USFS lands adjacent to the community of Easter Cove.

4.2 Treatment of Structural Ignitability

This section must be addressed in order for a CWPP to comply with the HFRA. This can be achieved through advocating defensible space, retrofitting existing structures with nonflammable materials, and ensuring future developments are fire resistant.

4.3 Public Outreach and Education

Texas Forest Service and USFWS developed a program to provide local libraries with educational materials on wildfire prevention and mitigation.
The USFS also has resources available for wildfire prevention and mitigation.

4.4 Emergency Facilities/Equipment Enhancement

Discuss any improvements (past, current, future) to local wildfire and emergency response capabilities. Texas Forest Service Regional Fire Coordinators can assist with improving the response capacity among local fire departments. More information on the various assistance programs can be found at http://texasforestservice.tamu.edu/fire/vfd/Default.asp or http://www.tamu.edu/ticc/coordinators.htm.

4.5 Emergency Response Plan/Evacuation Plan/ Wildfire Response Plan

- ***Discuss any plans developed for emergency response, wildfire response and evacuations. Local Emergency Management Coordinators should have records of any plans developed for that area.***
- ***Check to see if the local fire department has a Wildfire Pre-Attack plan in place. If not, work to develop one.***
- ***Look closely at communities with difficult access (1-way in/out, steep terrain, rough/narrow roads, etc.) and consider developing or improving evacuation plans for these communities.***

4.6 Evaluation of Restrictive Covenants and Ordinances

Determine if community/neighborhood covenants or ordinances allow for adequate defensible space around homes and within common areas.

4.7 Enhancement of Utilities and Infrastructure

Work with local community planners and utility companies to address any concerns with infrastructure.

4.8 Evaluate, Update and Maintain Planning Commitments

It is important to have a system for monitoring plan development. Use the check list provided in this guide, or develop one that suits the community's unique needs.

4.9 Development and Review of Memorandums of Understanding

In this section, determine what cooperative agreements exist between local, state and federal agencies with fire protection responsibilities. Encourage the development and use of MOUs to build additional cooperative networks and relationships, if needed.

4.10 Biomass/Utilization

Look for opportunities to enhance local economies through the use of natural resources produced or harvested by mitigation and restoration activities.

5.0 Implementation Tables

It is extremely important to determine who will be working on various portions of the CWPP. Most individuals involved in the planning process will be assisting on top of their normal activities; having a monitoring system in place system will ensure the plan stays on track.

5.1 Media Releases

5.1 Media Releases

Release Date	Format	Title	Author	Sent To:

5.2 Tracking of Progress/Fire Planning Checklist

Section	Category	Completed (√)	Date
1.	Introduction		
1.1	Collaborative/Planning Committee Members		
1.2	Statement of Intent		
1.3	Background		
1.4	Existing Situation/Current Risks		
1.5	Goals and Objectives		
1.6	Planning Process		
2.0	Community Profile		
2.1	Community Location		
2.2	Community Size		
2.3	Structures		
2.4	Population		
2.5	Community Legal Structure		
2.6	Utilities		
2.7	Emergency Response Capabilities		
2.8	Schools		
2.9	Emergency Medical Facilities		
2.10	Regulative Issues		
3.0	Community Risk Assessment		
3.1	Access		
3.2	Topography		
3.3	Fuels		
3.4	Construction		
3.5	Water Sources		
3.6	Expected Fire Behavior		
3.7	Community Hazard Rating		
3.8	Assets at Risk		
4.0	Community Prescription		
4.1	Hazardous Fuels Reduction Projects		
4.2	Treatment of Structural Ignitability		
4.3	Public Outreach and Education		
4.4	Emergency Facilities/Equipment Enhancement		
4.5	Emergency Response Plan/Evacuation Plan/ Wildfire Response Plan		

4.6	**Evaluation of Restrictive Covenants and Ordinances**		
4.7	**Enhancement of Utilities and Infrastructure**		
4.8	**Evaluate, Update and Maintain Planning Commitments**		
4.9	**Develop/Review/Revise Memorandums of Understanding**		
4.10	**Biomass/Utilization**		
5.0	**Implementation Tables**		
5.1	**Media Release**		
5.2	**Tracking of Progress/Fire Planning Checklist**		
6.0	**Declaration of Agreement and Concurrence**		
7.0	**Appendices**		

6.0 Declaration of Agreement and Concurrence

The following partners in the development of this Community Wildfire Protection Plan have reviewed and mutually agree on its contents:

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

7.0 Appendices

This section provides an example of a typical CWPP appendix. Use or modify this section based on the plan's specific contents.

A. Maps
- **Area Fuels Map**
- **Risk Assessment**
- **Fire History Maps/Historical Starts/Large Fire History**
- **Project Map**

B. Contact Lists
- **Formal Associations**
- **Media**
- **Utilities**
- **Schools**
- **Emergency Medical Facilities**
- **Funding Opportunities**

C. References & Acknowledgements
- **CWPP Summary and Checklist**
- **Community Fire Planning & Funding Resources**
- **Examples of Existing Plans**
- **Acronyms**
- **Glossary**

Appendix
Contact Lists

Formal Associations

List the contact information for churches, civic groups, volunteer service organizations, etc.

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Media Sources

List the contact information for local media and other outlets for public awareness.

Television

Name	Call Letters	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Radio

Name	Call Letters	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Newspaper

Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Other

Name	Type	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Utilities

List local utility companies incase utilities are threatened and need to be notified or shutoff.

ELECTRIC

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

GAS

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

WATER

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

TELEPHONE

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Schools

List all schools within the planning area, a member of the school board or the school's superintendent can provide you with this information.

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Emergency Medical Facilities

List local medical and mass care facilities in the area

Name		**Burn Unit?**	**Y or N**
Distance		**Shelter Use?**	**Y or N**
Contact Name		**Shelter In Place?**	**Y or N**
Phone Number			
Address			
Email Address			
Website			
Additional Info			

Name		**Burn Unit?**	**Y or N**
Distance		**Shelter Use?**	**Y or N**
Contact Name		**Shelter In Place?**	**Y or N**
Phone Number			
Address			
Email Address			
Website			
Additional Info			

Name		**Burn Unit?**	**Y or N**
Distance		**Shelter Use?**	**Y or N**
Contact Name		**Shelter In Place?**	**Y or N**
Phone Number			
Address			
Email Address			
Website			
Additional Info			

Funding Opportunities

Identify potential funding sources

Source	Type	Contact Name	Phone	Email

Texas Forest Service
Urban Wildland Interface Contacts

Texas Forest Service: http://texasforestservice.tamu.edu
Texas Interagency Coordination Center: http://www.tamu.edu/ticc
UWI Personnel Contact Information: http://www.tamu.edu/ticc/UWI_contacts.pdf
UWI General E-mail: texasuwi@tfs.tamu.edu
Risk Assessment Survey: http://www.tamu.edu/ticc/risk_assessment_survey.pdf

For more information, contact:

Texas Forest Service
Urban Wildland Interface Team
P.O. Box 1991
Bastrop, TX 78602
Phone: 512/321-2467
Fax: 512/321-4819
Email: texasuwi@tfs.tamu.edu
Website: http://texasforestservice.tamu.edu/

Or

Texas Forest Service
Justice Jones UWI Coordinator/ Project Leader
1328 FM 1488
Conroe, TX 77384
Phone: 936-273-2261
Fax 936/273-2282
jjjones@tfs.tamu.edu

CWPP Summary and Checklist

✓ **Step One: Convene Decision Makers**

- Form a core operating group with representation from the appropriate local governments, local fire authorities, and the state agency responsible for forest management.

✓ **Step Two: Involve and Engage Interested Parties**

- Contact and encourage active involvement in plan development from a broad range of interested organizations and stakeholders. (NOTE: This list provides a starting point and is by no means exclusive.)
    * City Council members
    * County Commissioners
    * Resource Advisory Committees
    * Texas Department of Transportation
    * Local and/or state emergency management agencies
    * Water districts – to identify key water infrastructure
    * Utilities
    * Recreation organizations
    * Environmental organizations
    * Forest products interests
    * Local Chambers of Commerce
    * Watershed councils
- Identify and engage local representatives of any federal land management agencies (i.e. USFS, USFWS, NPS, National Guard, etc.).
- Contact and involve other state and private land management agencies or organizations as appropriate (i.e. The Nature Conservancy, Texas Parks & Wildlife Department, prescribed fire co-ops, etc.).

✓ **Step Three: Establish a Community Base Map**

- Work with partners to establish a baseline map of the community that defines the community's UWI and displays inhabited areas at risk, and areas that contain critical human infrastructure.

✓ **Step Four: Develop a Community Risk Assessment and Identify Problems to Be Addressed**

- Work with partners to identify problems to be addressed:
  - * Fuel Hazards
  - * Risk of Wildfire Occurrence
  - * Homes, Businesses, and Essential Infrastructure at Risk
  - * Other Community Values at Risk
  - * Local Preparedness and Firefighting Capability
  - *
- This "community risk assessment" can be simple or complex depending on the resources available to the community and partners.

✓ **Step Five: Establish Community Priorities and Recommendations**

- Using the base map and community risk assessment to facilitate a collaborative community discussion, identify local priorities for:
- Fuel treatment
- Reducing structural ignitability, and
- Improving fire response capability

✓ **Step Six: Develop an Action Plan and Assessment Strategy**

- Consider developing a detailed implementation strategy to accompany the CWPP, as well as a monitoring plan that will ensure its long-term success.

✓ **Step Seven: Complete the Community Wildfire Protection Plan**

- When all the core members mutually agree on the plan, finalize the CWPP with a date stamp and signatures of the key representatives from the various cooperators.
- Communicate the results to the community and partners.
- Collect information to update the plan for revision the following year.

This checklist was adapted from the publication "Preparing a Community Wildfire Protection Plan: A handbook for Wildland-Urban Interface Communities" that can be downloaded from www.stateforesters.org/pubs/cwpphandbook.pdf **. The checklist was modified by the Texas Forest Service Urban Wildland Interface Team for use in Texas.**

Community Fire Planning & Funding Resources

Bureau of Land Management, Interim Guidance for Community Risk Assessment and Mitigation Plans, (2003)

Central Oregon Partnership for Wildfire Risk Reduction, Central Oregon Intergovernmental Council (December 2002), http://www.coic.org/copwrr/

Federal Emergency Management Agency (FEMA) Pre-Disaster Mitigation Program, Federal Register Vol. 67, No. 38, (Tuesday, February 26, 2002), http://www.access.gpo.gov/su_docs/fedreg/a020226c.html

Healthy Forests Restoration Act of 2003, Community Wildfire Protection Plans, http://agriculture.house.gov/h.r.1904confrpt.pdf

National Fire Plan, A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment 10-Year Comprehensive Strategy, (August 2001) http://www.fireplan.gov/reports/7-19-en.pdf

Partnership for Disaster Resistance and Resilience Community Pre-Disaster Mitigation Resources. http://csc.uoregon.edu/PDR_website/index.htm.

Utah Community Fire Planning for the Wildland Urban Interface, Utah Division of Forestry, Fire and State Lands, (2001) www.nr.utah.gov/SLF/fmcommunityfirepln.htm
Firewise, www.firewise.org

Living with fire- "A Homeowners Guide" – www.or.blm.gov/nwfire/doc/livingwithfire.pdf

Fire Safe Council- www.firesafe.org

Firewise Funding Source- www.firewise.org/usa/funding.htm

FEMA- "At Home in the Woods-Lessons Learned in the Wildland Urban Interface."- http://www.fema.gov/regions/viii/athome_woods.shtm

Examples of Existing Plans and Guides

- Virginia Department of Forestry An Action Plan for Wildfire Mitigation www.firewisevirginia.org
- Kentucky Firewise and Kentucky Division of Forestry, An Action Plan for Wildfire Mitigation http://www.forestry.ky.gov/
- Utah Division of Forestry, Fire and State Lands, Community Fire Planning for the Wildland-Urban Interface Guidance Document 2002
- Applegate Fire Plan, Applegate Partnership, (2002) http://www.grayback.com/applegate-valley/fireplan/index.asp
- California Fire Plan Template, California Community Fire Plan Workgroup, (July 2003), http://www.cafirealliance.org/downloads/CommunityFirePlanTemplate.pdf
- Colorado Springs, CO Plan, City of Colorado Springs, Colorado Springs Utilities, (2001), http://csfd.springsgov.com/wildfiremitigation.pdf
- Rogue River Regional Wildfire Hazard Mitigation/Response Plan, Rogue Valley Council of Governments, (September 2002), http://www.rvcog.org/
- Shoshone County Wildland Urban Interface Fire Mitigation Plan, Northwest Management, Inc., (October 2002)
- Trinity County Fire Management Plan, Trinity County Fire Safe Council, (February 2003), http://users.snowcrest.net/tcrcd/
- Colorado State Fire Plan, http://www.dola.state.co.us/oem/PublicInformation/wildfire.htm
- Jefferson County, Colorado Fire Plan, http://www.co.jefferson.co.us/ext/dpt/admin_svcs/emergmgmt/index.htm
- Josephine County Integrated Fire Plan, (ongoing, 2003-2004) http://www.co.josephine.or.us/wildfire/index.htm
- Lower Mattole Fire Plan, Mattole Restoration Council, (September 2002) http://www.mattole.org/html/publications_publication_2.html
- Southwest Community Wildfire Protection Plan Guide http://www.swsstrategy.org (2004)

Acronyms and Abbreviations

BMP	Best Management Practices
CR	County Road
CWPP	Community Wildfire Protection Plan
DEM	Department of Emergency Management
DOI	Department of the Interior
DOT	Department of Transportation
DPS	Department of Public Safety
DPW	Department of Public Works
EAS	Emergency Alert System
ESA	Endangered Species Act
EOC	Emergency Operations Center
DBH	diameter at breast height
EIS	Environmental Impact Statement (NEPA**)**
FD	Fire Department
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GPS	Global Positioning System
HFRA	Healthy Forests Restoration Act of 2003
IC	Incident Commander
ICP	Incident Command Post
ICS	Incident Command System
ISO	Insurance Service Office
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MAA	Mutual Aid Agreement
NEPA	National Environmental Policy Act
NFP	National Fire Plan
NPS	National Park Service
NRCS	Natural Resource Conservation Service
NWCG	National Wildfire Coordinating Group PIO Public Information Officer
PIO	Public Information Officer
RCW	Red Cockaded Woodpecker
RFA	Rural Fire Assistance
SFFMA	State Firefighters and Fire Marshals Association
SHPO	State Historic Preservation Office
SMZ	Streamside Management Zone
TCEQ	Texas Commission on Environmental Quality
TFS	Texas Forest Service
TICC	Texas Interagency Coordination Center
TNC	The Nature Conservancy
TPWD	Texas Parks & Wildlife Department
TXDOT	Texas Department of Transportation
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish & Wildlife Service
USGS	United States Geological Survey
UWI	Urban Wildland Interface
VFD	Volunteer Fire Department
WUI	Wildland Urban Interface (alternative to UWI)

Glossary

A

Aerial Fuels: All live and dead vegetation in the forest canopy or above the surface fuels, including tree branches, twigs and cones, snags, moss, and high brush.

Air Tanker: A fixed-wing aircraft equipped to drop fire retardants or suppressants.

Agency: Any federal, state, county or city organization participating with jurisdictional responsibilities.

Aspect: Direction toward which a slope faces.

B

Blow-up: A sudden increase in fire intensity or rate of spread strong enough to prevent direct control or to upset control plans. Blow-ups are often accompanied by violent convection and may have other characteristics of a fire storm.

Brush: A collective term that refers to stands of vegetation dominated by shrubby, woody plants, or low growing trees, usually of a type undesirable for livestock or timber management.

Brush Fire: A fire burning in vegetation that is predominantly shrubs, brush and scrub growth.

Buffer Zones: An area of reduced vegetation that separates wildland fuels from vulnerable residential or business developments. This barrier is similar to a greenbelt in that it is usually used for another purpose such as agriculture, recreation areas, parks, or golf courses.

Burning Ban: A declared ban on open air burning within a specified area, usually due to sustained high fire danger.

Burning Conditions: The state of the combined factors of the environment that affect fire behavior in a specified fuel type.

Burning Index: An estimate of the potential difficulty of fire containment as it relates to the flame length at the most rapidly spreading portion of a fire's perimeter.

Burning Period: That part of each 24-hour period when fires spread most rapidly, typically from 10:00 a.m. to sundown.

C

Chipping: Reducing wood related material by mechanical means into small pieces to be used as mulch or fuel. Chipping and mulching are often used interchangeably.

Chain: A unit of linear measurement equal to 66 feet.

Closure: Legal restriction, but not necessarily elimination of specified activities such as smoking, camping or entry that might cause fires in a given area.

Command Staff: The command staff consists of the information officer, safety officer and liaison officer. They report directly to the incident commander and may have assistants.

Complex: Two or more individual incidents located in the same general area which are assigned to a single incident commander or unified command.

Condition Class: The classification system used by the Forest Service to determine the extent of departure from the natural fire regime.

Condition Class I: A forest system within its natural fire range and at low risk for catastrophic fire.

Condition Class II: A forest that has moderately departed from its historic fire occurrence and is at moderate risk of experiencing losses to a wildfire.

Condition Class III: A forest that has departed from it historic fire regime and the risk of losing key habitat is high.

Cooperating Agency: An agency supplying assistance other than direct suppression, rescue, support, or service functions to the incident control effort; e.g., Red Cross, law enforcement agency, Telephone Company, etc.

Creeping Fire: Fire burning with a low flame and spreading slowly.

Crown Fire (Crowning): The movement of fire through the crowns of trees or shrubs more or less independently of the surface fire.

Curing: Drying and browning of herbaceous vegetation or slash.

D

Dead Fuels: Fuels with no living tissue in which moisture content is governed almost entirely by atmospheric moisture (relative humidity and precipitation), dry-bulb temperature, and solar radiation.

Debris Burning: A fire spreading from any fire originally set for the purpose of clearing land or for rubbish, garbage, range, stubble, or meadow burning.

Defensible Space: An area either natural or manmade where material capable of causing a fire to spread has been treated, cleared, reduced, or changed to act as a barrier between an advancing wildland fire and the loss to life, property, or resources. In practice, “defensible space” is defined as an area a minimum of 30 feet around a structure that is cleared of flammable brush or vegetation.

Detection: The act or system of discovering and locating fires.

Dozer: Any tracked vehicle with a front-mounted blade used for exposing mineral soil.

Dozer Line: Fire line constructed by the front blade of a dozer.

Drop Zone: Target area for air tankers, helitankers and cargo dropping.

Drought Index: A number representing net effect of evaporation, transpiration, and precipitation in producing cumulative moisture depletion in deep duff or upper soil.

Dry Lightning Storm: Thunderstorm in which negligible precipitation reaches the ground. Also called a dry storm.

Duff: The layer of decomposing organic materials lying below the litter layer of freshly fallen twigs, needles, and leaves immediately above the mineral soil.

E

Energy Release Component (ERC): The computed total heat released per unit area (British Thermal Units per square foot) within the fire front at the head of a moving fire.

Engine: Any ground vehicle providing specified levels of pumping, water and hose capacity.

Engine Crew: Firefighters assigned to an engine. The Fireline Handbook defines the minimum crew makeup by engine type.

Entrapment: A situation where personnel are unexpectedly caught in a fire behavior-related, life threatening position where planned escape routes or safety zones are absent, inadequate or compromised. An entrapment may or may not include deployment of a fire shelter for its intended purpose. These situations may or may not result in injury. They include “near misses”.

Environmental Assessment (EA): Eva’s were authorized by the National Environmental Policy Act (NEPA) of 1969. They are concise, analytical documents prepared with public participation that determine if an Environmental Impact Statement (EIS) is needed for a particular project or action. If an EA determines an EIS is not needed, the EA becomes the document allowing agency compliance with NEPA requirements.

Environmental Impact Statement (EIS): EISs were authorized by the National Environmental Policy Act (NEPA) of 1969. Prepared with public participation, they assist decision makers by providing information, analysis and an array of action alternatives, allowing managers to see the probable effects of decisions on the environment. Generally, EISs are written for large-scale actions or geographical areas.

Escape Route: A preplanned and understood route firefighters take to move to a safety zone or other low-risk area, such as an already burned area, previously constructed safety area, a meadow that won’t burn, natural rocky area that is large enough to take refuge without being burned. When escaped routes deviate from a defined physical path, they should be clearly marked (flagged).

Escaped Fire: A fire which has exceeded or is expected to exceed initial attack capabilities or prescription.

Extended Attack Incident: A wildland fire that has not been contained or controlled by initial attack forces and for which more firefighting resources are arriving, en route, or being ordered by the initial attack incident commander.

Extreme Fire Behavior: “Extreme” implies a level of fire behavior characteristics that ordinarily precludes methods of direct control action. One or more of the following is usually involved: high rate of spread, prolific crowning and/or spotting, presence of fire whirls, strong convection column. Predictability is difficult because such fires often exercise some degree of influence on their environment and behave erratically, sometimes dangerously.

F

Fingers of a Fire: The long narrow extensions of a fire projecting from the main body.

Fire Behavior: The manner in which a fire reacts to the influences of fuel, weather and topography.

Fire Behavior Forecast: Prediction of probable fire behavior usually prepared by a Fire Behavior Officer, in support of fire suppression or prescribed burning operations.

Fire Break: A natural or constructed barrier used to stop or check fires that may occur, or to provide a control line from which to work.

Fire Cache: A supply of fire tools and equipment assembled in planned quantities or standard units at a strategic point for exclusive use in fire suppression.

Fire Crew: An organized group of firefighters under the leadership of a crew leader or other designated official.

Fire Front: The part of a fire within which continuous flaming combustion is taking place. Unless otherwise specified the fire front is assumed to be the leading edge of the fire perimeter. In ground fires, the fire front may be mainly smoldering combustion.

Fire Intensity: A general term relating to the heat energy released by a fire.

Fire Line: A linear fire barrier that is scraped or dug to mineral soil.

Fire Load: The number and size of fires historically experienced on a specified unit over a specified period (usually one day) at a specified index of fire danger.

Fire Management Plan (FMP): A strategic plan that defines a program to manage wildland and prescribed fires and documents the Fire Management Program in the approved land use plan. The plan is supplemented by operational plans such as preparedness plans, preplanned dispatch plans, prescribed fire plans, and prevention plans.

Fire Perimeter: The entire outer edge or boundary of a fire

Fire Regime: A natural fire regime is a classification of the role that fire would play across a landscape in the absence of human intervention.

Fire Season: 1) Period(s) of the year during which wildland fires are likely to occur, spread, and affects resource values sufficient to warrant organized fire management activities. 2) A legally enacted time during which burning activities are regulated by state or local authority.

Fire Storm: Violent convection caused by a large continuous are of intense fire. Often characterized by destructively violent surface in drafts, near and beyond the perimeter, and sometimes by tornado-like whirls.

Fire Triangle: Instructional aid in which the sides of a triangle are used to represent the three factors (oxygen, heat, fuel) necessary for combustion and flame production; removal of any of the three factors causes flame production to cease.

Fire Weather: Weather conditions that influence fire ignition, behavior and suppression.

Fire Weather Watch: A term used by fire weather forecasters to notify using agencies, usually 24 to 72 hours ahead of the event, that current and developing meteorological conditions may evolve into dangerous fire weather.

Fire Whirl: Spinning vortex column of ascending hot air and gases rising from a fire and carrying aloft smoke, debris and flame. Fire whirls range in size from less that one foot to more than 500 feet in diameter. Large fire whirls have the intensity of a small tornado.

Firefighting Resources: All people and major items of equipment that can or potentially could be assigned to fires.

Flame Height: The average maximum vertical extension of flames at the leading edge of the fire front. Occasional flashes that rise about the general level of flames are not considered. This distance is less than the flame length if flames are tilted due to wind of slope.

Flame Length: The distance between the flame tip and the midpoint of the flame depth at the base of the flame (generally the ground surface); an indicator of fire intensity.

Flaming Front: The zone of a moving fire where the combustion is primarily flaming. Behind this flaming zone combustion is primarily glowing. Light fuels typically have a shallow flaming front, whereas heavy fuels have a deeper front. Also called fire front.

Flanks of a Fire: The parts of a fire's perimeter that are roughly parallel to the main direction of spread.

Flare-up: Any sudden acceleration of fire spread or intensification of a fire. Unlike a blow-up, a flare-up lasts a relatively short time and does not radically change control plans.

Future Desired Conditions: The future desired conditions on federal land is a return to Condition Class I. (see Condition Class 1)

Flash Fuels: Fuels such as grass, leaves, draped pine needles, fern, tree moss and some kinds of slash, that ignite readily and are consumed rapidly when dry. Also called fine fuels.

Forbs: Plants with a soft, rather than permanent woody stem, that is not a grass or grass-like plant.

Fuel: Combustible material. This includes, vegetation, such as grass, leaves, ground litter, plants shrubs and trees, which feed a fire.

Fuel Bed: An array of fuels usually constructed with specific loading, depth, and particle size to meet experimental requirements; also, commonly used to describe the fuel composition in natural settings.

Fuel Loading: The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area.

Fuel Model: Simulated fuel complex (or combination of vegetation types) for which all fuel descriptors required for the solution of a mathematical rate of spread model has been specified

Fuel Moisture (Fuel Moisture Content): The quantity of moisture in fuel expressed as a percentage of the weight when thoroughly dried at 212 degrees Fahrenheit

Fuel Reduction: Manipulation, including combustion, or removal of fuels to reduce the likelihood of ignition and/or to lessen potential damage and resistance to control.

Fuel Type: An identifiable association of fuel elements of a distinctive plant species, form, size, arrangement, or other characteristics that will cause a predictable rate of fire spread or difficulty of control under specified weather conditions.

G

Geographic Area: A political boundary designated by the wildland fire protection agencies where these agencies work together in the coordination and effective utilization.

Ground Fuel: All combustible materials below the surface litter, including duff, tree or shrub roots, punch wood, peat, and sawdust that normally support a glowing combustion without flame.

H

Haines Index: An atmospheric index used to indicate the potential for wildfire growth by measuring the stability and dryness of the air over a fire.

Hand Line: A fireline built with hand tools.

Hazard Reduction: Any treatment of a hazard that reduces the threat of ignition and fire intensity or rate of spread.

Head of a Fire: The side of the fire having the fastest rate of spread.

Heavy Fuels: Fuels of large diameter such as snags, logs, large limb wood, that ignite and are consumed more slowly than flash fuels.

Helibase: The main location within the general incident area for parking, fueling, maintaining, and loading helicopters. The helibase is usually located at or near the incident base.

Helispot: A temporary landing spot for helicopters.

Hotspot: A particular active part of a fire.

Hot spotting: Reducing or stopping the spread of fire at points of particularly rapid rate of spread or special threat, generally the first step in prompt control, with emphasis on first priorities.

I

Incident: A human-caused or natural occurrence, such as wildland fire, that requires emergency service action to prevent or reduce the loss of life or damage to property or natural resources.

Incident Action Plan (IAP): Contains objectives reflecting the overall incident strategy and specific tactical actions and supporting information for the next operational period. The plan may be oral or written. When written, the plan may have a number of attachments, including but not limited to: incident objectives, organization assignment list, division assignment, incident radio communication plan, medical plan, traffic plan, safety plan, and incident map.

Incident Command Post (ICP): Location at which primary command functions are executed. The ICP may be co-located with the incident base or other incident facilities.

Incident Command System (ICS): The combination of facilities, equipment, personnel, procedure and communications operating within a common organizational structure, with responsibility for the management of assigned resources to effectively accomplish stated objectives pertaining to an incident.

Incident Commander: Individual responsible for the management of all incident operations at the incident site.

Initial Attack: The actions taken by the first resources to arrive at a wildfire to protect lives and property, and prevent further extension of the fire.

J

Job Hazard Analysis: This analysis of a project is completed by staff to identify hazards to employees and the public. It identifies hazards, corrective actions and the required safety equipment to ensure public and employee safety.

K

Keech Byram Drought Index (KBDI): Commonly-used drought index adapted for fire management applications, with a numerical range from 0 (no moisture deficiency) to 800 (maximum drought).

L

Ladder Fuels: Fuels which provide vertical continuity between strata, thereby allowing fire to carry from surface fuels into the crowns of trees or shrubs with relative ease. They help initiate and assure the continuation of crowning.

Light (Fine) Fuels: Fast-drying fuels, generally with comparatively high surface area-to-volume ratios, which are less than ¼-inch in diameter and have a time lag of one hour or less. These fuels readily ignite and are rapidly consumed by fire when dry.

Lightning Activity Level (LAL): A number, on a scale of 1 to 6 that reflects frequency and character of cloud-to-ground lightning. The scale is exponential based on powers of 2 (i.e., LAL 3 indicates twice the lightning of LAL 2).

Litter: Top layer of the forest, scrubland, or grassland floor, directly above the fermentation layer, composed of loose debris of dead sticks, branches, twigs, and recently fallen leaves or needles, little altered in structure by decomposition.

Live Fuels: Living plants, such as trees, grasses, and shrubs, in which the seasonal moisture content cycle is controlled largely by internal physiological mechanisms rather than by external weather influences.

M

Mineral Soil: Soil layers below the predominantly organic horizons; soil with little combustible material.

Mobilization: The process and procedures used by all organizations, federal, state and local for activating, assembling, and transporting all resources that have been requested to respond to or support an incident.

Mop-up: To make a fire safe or reduce residual smoke after the fire has been controlled by extinguishing or removing burning material along or near the control line, felling snags, or moving logs so they won't roll downhill.

Multi-Agency Coordination (MAC): A generalized term which describes the functions and activities of representatives of involved agencies and/or jurisdictions who come together to make decisions regarding the prioritizing of incidents, and the sharing and use of critical resources. The MAC organization is not a part of the on-scene ICS and is not involved in developing incident strategy or tactics.

Mutual Aid Agreement: Written agreement between agencies and/or jurisdictions in which they agree to assist one another upon request, by furnishing personnel and equipment.

N

National Environmental Policy Act (NEPA): NEPA is the basic national law for protection of the environment, passed by Congress in 1969. It sets policy and procedures for environmental protection, and authorizes Environmental Impact Statements and Environmental Assessments to be used as analytical tools to help federal managers make decisions.

National Fire Danger Rating System (NFDRS): A uniform fire danger rating system that focuses on the environmental factors that control the moisture content of fuels.

National Wildfire Coordinating Group: A group formed under the direction of the Secretaries of Agriculture and the Interior and comprised of representatives of the U.S. Forest Service, Bureau of Land Management, Bureau of Indian Affairs, National Park Service, U.S. Fish and Wildlife Service and Association of State Foresters. The group's purpose is to facilitate coordination and effectiveness of wildland fire activities and provide a forum to discuss, recommend action, or resolve issues and problems of substantive nature. NWCG is the certifying body for all courses in the National Fire Curriculum.

Normal Fire Season: 1) A season when weather, fire danger, and number and distribution of fires are about average. 2) Period of the year that normally comprises the fire season.

O

Operational Period: The period of time scheduled for execution of a given set of tactical actions as specified in the Incident Action Plan. Operational periods can be of various lengths, although usually not more than 24 hours.

Overhead: People assigned to supervisory positions, including incident commanders, command staff, general staff, directors, supervisors, and unit leaders.

P

Peak Fire Season: That period of the fire season during which fires are expected to ignite most readily, to burn with greater than average intensity, and to create damages at an unacceptable level.

Preparedness: Condition or degree of being ready to cope with a potential fire situation.

Prescribed Fire: Any fire ignited by management actions under certain, predetermined conditions to meet specific objectives related to hazardous fuels or habitat improvement. A written, approved prescribed fire plan must exist, and NEPA requirements must be met, prior to ignition.

Prescribed Fire Plan (Burn Plan): This document provides the prescribed fire burn boss information needed to implement an individual prescribed fire project.

Prescription: Measurable criteria that define conditions under which a prescribed fire may be ignited, guide selection of appropriate management responses, and indicate other required actions. Prescription criteria may include safety, economic, public health, environmental, geographic, administrative, social, or legal considerations.

Prevention: Activities directed at reducing the incidence of fires, including public education, law enforcement, personal contact, and reduction of fuel hazards.

R

Radiant Burn: A burn received from a radiant heat source.

Rate of Spread: The relative activity of a fire in extending its horizontal dimensions. It is expressed as a rate of increase of the total perimeter of the fire, as rate of forward spread of the fire front, or as rate of increase in area, depending on the intended use of the information. Usually it is expressed in chains or acres per hour for a specific period in the fire's history.

Reburn: The burning of an area that has been previously burned but that contains flammable fuel that ignites when burning conditions are more favorable; an area that has reburned.

Red Flag Warning: Term used by fire weather forecasters to alert forecast users to an ongoing or imminent critical fire weather pattern.

Rehabilitation: The activities necessary to repair damage or disturbance caused by wildland fires or the fire suppression activity.

Relative Humidity (Rh): The ratio of the amount of moisture in the air, to the maximum amount of moisture that air would contain if it were saturated. The ratio of the actual vapor pressure to the saturated vapor pressure.

Remote Automatic Weather Station (RAWS): An apparatus that automatically acquires, processes, and stores local weather data for later transmission to the GOES Satellite, from which the data is re-transmitted to an earth-receiving station for use in the National Fire Danger Rating System.

Resources: 1) Personnel, equipment, services and supplies available, or potentially available, for assignment to incidents. 2) The natural resources of an area, such as timber, crass, watershed values, recreation values, and wildlife habitat.

Resource Management Plan (RMP): A document prepared by field office staff with public participation and approved by field office managers that provides general guidance and direction for land management activities at a field office. The RMP identifies the need for fire in a particular area and for a specific benefit.

Retardant: A substance or chemical agent which reduced the flammability of combustibles.

Run (of a fire): The rapid advance of the head of a fire with a marked change in fire line intensity and rate of spread from that noted before and after the advance.

S

Safety Zone: An area cleared of flammable materials used for escape in the event the line is outflanked or in case a spot fire causes fuels outside the control line to render the line unsafe. In firing operations, crews progress so as to maintain a safety zone close at hand allowing the fuels inside the control line to be consumed before going ahead. Safety zones may also be constructed as integral parts of fuel breaks; they are greatly enlarged areas which can be used with relative safety by firefighters and their equipment in the event of a blowup in the vicinity.

Severity Funding: Funds provided to increase wildland fire suppression response capability necessitated by abnormal weather patterns, extended drought, or other events causing abnormal increase in the fire potential and/or danger.

Single Resource: An individual, a piece of equipment and its personnel complement, or a crew or team of individuals with an identified work supervisor that can be used on an incident.

Size-up: To evaluate a fire to determine a course of action for fire suppression.

Slash: Debris left after logging, pruning, thinning or brush cutting; includes logs, chips, bark, branches, stumps and broken understory trees or brush.

Slop-over: A fire edge that crosses a control line or natural barrier intended to contain the fire.

Smoke Management: Application of fire intensities and meteorological processes to minimize degradation of air quality during prescribed fires.

Snag: A standing dead tree or part of a dead tree from which at least the smaller branches have fallen.

Spark Arrester: A device installed in a chimney, flue, or exhaust pipe to stop the emission of sparks and burning fragments.

Spot Fire: A fire ignited outside the perimeter of the main fire by flying sparks or embers.

Spot Weather Forecast: A special forecast issued to fit the time, topography, and weather of each specific fire. These forecasts are issued upon request of the user agency and are more detailed, timely, and specific than zone forecasts.

Spotting: Behavior of a fire producing sparks or embers that are carried by the wind and start new fires beyond the zone of direct ignition by the main fire.

Staging Area: Locations set up at an incident where resources can be placed while awaiting a tactical assignment on a three-minute available basis. Staging areas are managed by the operations section.

Strategy: The science and art of command as applied to the overall planning and conduct of an incident.

Structure Fire: Fire originating in and burning any part or all of any building, shelter, or other structure.

Suppressant: An agent, such as water or foam, used to extinguish the flaming and glowing phases of combustion when direction applied to burning fuels.

Suppression: All the work of extinguishing or containing a fire, beginning with its discovery.

Surface Fuels: Loose surface litter on the soil surface, normally consisting of fallen leaves or needles, twigs, bark, cones, and small branches that have not yet decayed enough to lose their identity; also grasses, forbs, low and medium shrubs, tree seedlings, heavier branchwood, downed logs, and stumps interspersed with or partially replacing the litter.

T

Tactics: Deploying and directing resources on an incident to accomplish the objectives designated by strategy.

Temporary Flight Restrictions (TFR): A restriction requested by an agency and put into effect by the Federal Aviation Administration in the vicinity of an incident which restricts the operation of nonessential aircraft in the airspace around that incident.

Torching: The ignition and flare-up of a tree or small group of trees, usually from bottom to top.

Type: The capability of a firefighting resource in comparison to another type. Type 1 usually means a greater capability due to power, size, or capacity.

U

Uncontrolled Fire: Any fire which threatens to destroy life, property, or natural resources.

Under burn: A fire that consumes surface fuels but not trees or shrubs. (See Surface Fuels.)

V

Volunteer Fire Department (VFD): A fire department of which some or all members are unpaid.

W

Water Tender: A ground vehicle capable of transporting specified quantities of water.

Wildland Fire: Any nonstructural fire, other than prescribed fire, that occurs in the wildland.

Wildland Fire Implementation Plan (WFIP): A progressively developed assessment and operational management plan that documents the analysis and selection of strategies and describes the appropriate management response for a wildland fire being managed for resource benefits.

Wildland Fire Use: The management of naturally ignited wildland fires to accomplish specific pre-stated resource management objectives in predefined geographic areas outlined in Fire Management Plans.

Wildland Urban Interface: The line, area or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels.

A Template for Developing Community Wildfire Protection Plans

In Accordance with Title I of The Healthy Forest Restoration Act of 2003



TEXAS FOREST SERVICE
The Texas A&M University System

A collaborative approach to help protect life, property and natural resources through community-based planning

Table of Contents

1.0 Introduction

1.1 Collaboration

This Community Wildfire Protection Plan is a collaborative effort between the following entities. The representatives listed below comprise the core decision-making team responsible for this report and mutually agree on the plan's contents.

Community Representative(s):

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Local Fire Department Representatives:

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Texas Forest Service UWI Representative(s):

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Federal Agency Representative(s):

Name	
Address	
Telephone Number(s)	
Other Contact Information	

Name	
Address	
Telephone Number(s)	
Other Contact Information	

1.2 Statement of Intent

1.3 Historical Fire Occurrence

1.4 Existing Situation / Current Risks

1.5 Goals and Objectives

1.6 Planning Process

2.0 Community Profile

2.1 Community Location

County	
Latitude/Longitude	
Plan Area and Unit Boundaries	
Frontage and/or Perimeter Road(s)	
Additional Landmarks	

2.2 Community Size

Acreage						
Square Miles						
Number of Lots	TOTAL		Developed		Undeveloped	

2.3 Structures

Type	Number or Percentage
Homes	
Mobile Homes	
Outbuildings	
Commercial Buildings	
Abandoned Buildings	

2.4 Population

Total Population: ___________
Full Time Residents:__________%
Part Time Residents:__________%

2.5 Community Legal Structure

Organization	Contact, Title	Phone Numbers	Email Address(es)

2.6 Utilities

2.7 Emergency Response Capabilities

Local	*Department Name Address*	*Contact Name Title Email*	*Phone Numbers*

Resources		**Response Time**	
Engines Type / ID / Capacity	**Dozers & Tractor Plows Type / ID /**	**Misc. (Tankers/Tenders, Etc.) / Capacity**	**Aviation Type / ID / Capacity**

State	*Department Name Address*	*Contact Name Title Email*	*Phone Numbers*

Resources		**Response Time**	
Engines Type / ID / Capacity	**Dozers & Tractor Plows Type / ID /**	**Misc. (Tankers/Tenders, Etc.) / Capacity**	**Aviation Type / ID / Capacity**

Federal	*Department Name Address*	*Contact Name Title Email*	*Phone Numbers*

Resources		**Response Time**	
Engines Type / ID / Capacity	**Dozers & Tractor Plows Type / ID /**	**Misc. (Tankers/Tenders, Etc.) / Capacity**	**Aviation Type / ID / Capacity**

2.8 Schools

2.9 Emergency Medical Facilities

2.10 Regulative Issues

3.0 Community Risk Assessment

3.1 Access

3.2 Topography

3.3 Fuels

3.4 Construction

3.5 Water Sources

3.6 Expected Fire Behavior

3.7 Community Hazard Rating

Low / Medium / High

3.8 Assets at Risk

3.8.1 Natural Resources

PLANT Name (Common/Scientific)	T & E Status	Priority
Discussion:		

ANIMAL Name (Common/Scientific)	T & E Status	Priority
	Endangered	High
Discussion:		

Watershed/Wetland Considerations	Priority
Discussion:	

3.8.2 Commercial & Industrial Resources

Resource	Priority
Discussion:	

3.8.3 Community Values & Cultural Assets

Resource	Priority
Discussion:	

3.8.4 Estimated Values at Risk

Resource	Estimated value
	$
	$
	$
Discussion:	

4.0 Community Prescription

4.1 Hazardous Fuels Reduction Project

4.2 Treatment of Structural Ignitability

4.3 Public Outreach and Education

4.4 Emergency Facilities/Equipment Enhancement

4.5 Emergency Response Plan/Evacuation Plan/Wildfire Response Plan

4.6 Evaluation of Restrictive Covenants and Ordinances

4.7 Enhancement of Utilities and Infrastructure

4.8 Evaluate, Update and Maintain Planning Commitments

4.9 Development and Review of Memorandums of Understanding

4.10 Biomass / Utilization

5.0 Implementation Tables

5.1 Media Releases

5.1 Media Release

Release Date	Format	Title	Author	Sent To:

5.2 Tracking of Progress/Fire Planning Checklist

Section	Category	Completed (√)	Date
1.	Introduction		
1.1	Collaborative/Planning Committee Members		
1.2	Statement of Intent		
1.3	Background		
1.4	Existing Situation/Current Risks		
1.5	Goals and Objectives		
1.6	Planning Process		
2.0	Community Profile		
2.1	Community Location		
2.2	Community Size		
2.3	Structures		
2.4	Population		
2.5	Community Legal Structure		
2.6	Utilities		
2.7	Emergency Response Capabilities		
2.8	Schools		
2.9	Emergency Medical Facilities		
2.10	Regulative Issues		
3.0	Community Risk Assessment		
3.1	Access		
3.2	Topography		
3.3	Fuels		
3.4	Construction		
3.5	Water Sources		
3.6	Expected Fire Behavior		
3.7	Community Hazard Rating		
3.8	Assets at Risk		
4.0	Community Prescription		
4.1	Hazardous Fuels Reduction Project		
4.2	Treatment of Structural Ignitability		

4.3	**Public Outreach and Education**		
4.4	**Emergency Facilities/Equipment Enhancement**		
4.5	**Emergency Response Plan/Evacuation Plan/ Wildfire Response Plan**		
4.6	**Evaluation of Restrictive Covenants and Ordinances**		
4.7	**Enhancement of Utilities and Infrastructure**		
4.8	**Evaluate, Update and Maintain Planning Commitments**		
4.9	**Develop/Review/Revise Memorandums of Understanding (MOUs)**		
4.10	**Biomass / Utilization**		
5.0	**Implementation Tables**		
5.1	**Media Release**		
5.2	**Tracking of Progress/Fire Planning Checklist**		
6.0	**Declaration of Agreement and Concurrence**		
7.0	**Appendices**		

6.0 Declaration of Agreement and Concurrence

The following partners in the development of this Community Wildfire Protection Plan have reviewed and mutually with its contents:

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

Signature **Date**

Name, Title, Agency/Organization

7.0 Appendices

A. **Maps**
- **Area Fuels Map**
- **Risk Assessment**
- **Fire History Maps/Historical Starts/Large Fire History**
- **Project Map**

B. **Contact Lists**
- **Formal Associations**
- **Media**
- **Utilities**
- **Schools**
- **Emergency Medical Facilities**
- **Funding Opportunities**
- **TFS UWI Contacts**

C. **References & Acknowledgements**
- **CWPP Summary and Checklist**
- **Community Fire Planning & Funding Resources**
- **Examples of Existing Plans**
- **Credits and Acknowledgements**
- **Acronyms**
- **Glossary**

Appendix B
Contact Lists

Formal Associations

List the contact information for churches, civic groups, volunteer service organizations, etc.

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Name	
Contact Person	
Telephone Number	
Other Contact Information	

Media Sources

List the contact information for local media and other outlets for public awareness.

Television

Name	Call Letters	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Radio

Name	Call Letters	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Newspaper

Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Other

Name	Type	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Utilities

ELECTRIC

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

GAS

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

WATER

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

TELEPHONE

Company Name	City	Contact (Name/Title)	Phone/Fax Number	Email Address	Website

Schools

List all schools within the planning area, a member of the school board or the school's superintendent can provide you with this information.

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Name		**Shelter Use?**	**Y or N**
Principal		**Shelter In Place?**	**Y or N**
Contact Name			
Address			
Phone Number			
Email Address			
Website			

Emergency Medical Facilities

Name		Burn Unit?	Y or N
Distance		Shelter Use?	Y or N
Contact Name		Shelter In Place?	Y or N
Phone Number			
Address			
Email Address			
Website			
Additional Info			

Name		Burn Unit?	Y or N
Distance		Shelter Use?	Y or N
Contact Name		Shelter In Place?	Y or N
Phone Number			
Address			
Email Address			
Website			
Additional Info			

Name		Burn Unit?	Y or N
Distance		Shelter Use?	Y or N
Contact Name		Shelter In Place?	Y or N
Phone Number			
Address			
Email Address			
Website			
Additional Info			

Funding Opportunities

Identify potential funding sources

Source	Type	Contact Name	Phone	Email

CWPP Enhancement Guidance – *Lessons Learned!*

After reviewing many Community Wildfire Protection Plans (CWPPs), we have concluded most could provide greater benefits to the participants with a few modifications. We encourage CWPP developers to consider the following recommendations.

Formal Agreement

The Healthy Forest Restoration Act of 2003 (HFRA) requires a CWPP be "agreed to by the applicable local government, local fire department, and State agency responsible for forest management" (CDF in California). While not required, we suggest a formal agreement, such as the Wildfire Protection Plan Certification and Agreement Signature Sheet will add clarity that the CWPP is authentic. It will also indicate that the included projects are supported by the community and ready for implementation.

Designate a Generous WUI

HFRA provides communities the opportunity to designate a locally appropriate definition and boundary for the Wildland Urban Interface (WUI). The default definition is ½ to 1½ miles from the boundary of an at-risk community, depending on slope, geographic features and condition class or an area that is adjacent to an evacuation route. HFRA includes advantages for communities that designate larger WUIs by providing streamlined NEPA documentation for projects that are greater than 1½ miles from the community but within the community designated WUI. A community designated WUI of 1½ miles loses this advantage. A plan in New Mexico established WUI boundaries 15 miles from the community.

Include Federal Projects

One of the purposes of HFRA is "to reduce wildfire risk to communities, municipal water supplies, and other at-risk Federal land through a collaborative process of planning, prioritizing, and implementing hazardous fuel reduction projects" (emphasis added). Accordingly, HFRA provides for meaningful community participation in federal project planning through the opportunity to recommend projects on federal lands. When Federal agencies implement the community recommendations, the NEPA process is streamlined, reducing planning time and expenses. An easy method to realize this benefit is to consider all federal projects near a community that are in some stage of planning development. Considering planned federal projects also helps meeting the requirement to consult with Federal land management agencies. The community may recommend changes to the scope of the projects or method of treatments. Communities may also recommend additional projects. The greatest benefit will be for those projects that NEPA has not yet begun.

Include Revenue Generating Projects

The CWPP provision is designed to coordinate efforts to reduce fire risk among all landowners. Some CWPPs have included only projects that require grant funding, which limits the opportunity for a coordinated approach to fire risk reduction. It also limits the opportunity for community members to recommend a community fuel reduction strategy and expedited implementation of federal and private projects.

Include Projects outside the WUI

Another purpose of HFRA is "to enhance efforts to protect watersheds and address threats to forest and rangeland health, including catastrophic wildfire, across the landscape." Just as projects within a WUI, CWPPs provide meaningful community participation in developing recommendations for private and federal projects outside the WUI. Private and Federal land managers also receive similar (but reduced) benefits to implementing the community recommendations as they do with projects within the WUI.

Recommend Treatment Types and Methods

HFRA requires CWPPs to "recommend the types and methods of treatment on Federal and non-Federal land that will protect 1 or more at-risk communities and essential infrastructure." Treatment recommendations are part of the NEPA and CEQA process. Community recommendations are necessary for land managers to realize the streamlined processes. Additionally, the greatest controversy frequently revolves around treatment recommendations. Providing recommendations for the type and method of treatment that the community will support focuses land owner attention on community acceptable land management practices. Treatment recommendations can be project specific, or area-wide.

Leaders Guide for developing a Community Wildfire Protection Plan

This Leaders Guide was created for Leaders by Leaders and is designed to work directly with "Preparing a Community Wildfire Protection Plan – Handbook" available at: www.safnet.org/policyandpress/cwpp.cfm

Leaders Guide General Instructions

This Leaders Guide is designed to supplement the document entitled: "*Preparing a Community Wildfire Protection Plan – Handbook for Wildland-Urban Interface Communities*" available at www.safnet.org/policyandpress/cwpp.cfm or contact the Western Governors' Association at (303)-623-9378 for a free copy. Please reference the Leaders Guide Supplement for details about each of the step instructions listed on this Fire Chiefs / Leaders Guide. www.iafc.org

Minimum CWPP requirements
As required by the Healthy Forests Restoration Act:

1. Collaboration*: local and state government agencies in consultation with federal agencies and other interested parties
2. Prioritized Fuel Reduction: identify and prioritize areas for hazardous fuel reduction; recommend types of treatment; must protect one or more at-risk communities and essential infrastructure
3. Treatment of Structural Ignitability: A CWPP must recommend measures for homeowners and communities to reduce ignitability of structures

***Collaboration:**

More than asking for feedback - must plan, do and act together; three entities must mutually agree: local government, local fire department(s), and state entity responsible for forest management. In addition, must consult with local representatives from USFS/USDA and BLM/DOI and other interested parties or persons in the development of the plan.

Timeline for first CWPP

The first draft of the CWPP can be accomplished with 6 well planned meetings and will take approximately 1- 18 months to complete the CWPP process. Consider a strategy of developing a simple version of the CWPP that you can "Plan – Do – and Act" on with smaller successes. This will lead to larger outcomes as the plan is expanded in the future.

Leaders Guide Symbols:

- **P** Plan symbol - vision, knowledge, network, scope and planned activities.
- **D** Do symbol - activities accomplished to gain a planned outcome
- **A** Act symbol numerically indexed; A planned activity that is ready for action/implementation

Phase 1: Forming and Norming

Step #1 Convene Decision-makers: Form a core team of representatives from local government, local fire, and state agency responsible for forest management

- **D** Staff meeting review of CWPP process; brainstorm methods and who to invite to the planning process
- **P** Fire Chief/Leader to decide the need for a CWPP; consult with neighboring fire chiefs
- **P** Develop conceptual mission and policy direction for CWPP
- **D** List lead planning team: local, state and federal agencies; local community leaders
- **P** Define jurisdictional and non-jurisdictional players and match them to the wildland fire problems
- **P** Identify core group of policy leaders, statutory authorities; those with sign off powers; granting agencies
- **P** Review local, state and federal wildfire plans and the City/County General Plan Safety Element
- **D** Face to face meetings with city and county executive and political leaders – check the level of support for the CWPP
- **P** Begin defining the geographical planning area for the CWPP

Step #2 Involve Federal Agencies: Identify and engage local representative of the USFS and DOI; contact other land management agencies as appropriate. Public Releases

- **D** Define property ownership in the CWPP planning area.
- **P** Work with state and federal agencies for grant opportunities
- **P** Contact local agencies that have completed a CWPP
- **A** Assign the official CWPP planning team for the first meeting. Involve the public early and continuously
- **D** Face to face meeting with state, federal and regional leaders that have a property interest in completing a CWPP – discuss the need to form a planning team and to access available grant funds

Step #3 Engage Interested Parties: Contact and encourage active involvement in plan development from a broad range of interested organizations and stakeholders.

- **D** Personal invitation to property owners and a broad range ofstakeholder groups to join the planning process
- **P** Find meeting locations and convenient meeting times
- **D** Develop the agenda for the first meeting
- **A** Convene the first CWPP meeting: introduce planning process; describe benefits of doing a CWPP; expand planning team membership; and encourage support and involvement
- **P** Leadership to assure CWPP process is on the right track and empower other leaders to keep process on track
- **P** Leadership to encourage members of the planning group to stay engaged; encourage the non-participants to engage and speak out; make sure the non-fire representatives are invited
- **P** Understand and be ready to address the "deal stopper" issues; be ready to keep planning team focused on the mission and vision of the planning process
- **D** Refine the mission and direction of the planning process to accurately reflect the community concern.

SPONSORED BY:

National Association of State Foresters • International Association of Fire Chiefs • The Wilderness Society

THE WILDERNESS SOCIETY

Phase 2: Risk Assessment and Priority Setting

Step #4 Establish a Community Base Map: Work with partners to establish a baseline map of the community that defines the community WUI, inhabited areas at risk, forested areas containing critical human infrastructure, and forest areas at risk for large-scale fire disturbance.

- **P** Start with any base map; define the CWPP planning area – use natural and recognizable boundary breaks
- **A** Convene the second CWPP meeting and focus on defining the fuel hazards, assets at risk and confirm the planning area; make sure that the planning team understands the mission and vision of the CWPP process

Step #5 Develop a Community Risk Assessment: Work with planning partners to develop a community risk assessment that considers fuel hazards; risk of wildfire occurrence; homes, businesses, and essential infrastructure at risk; other community values at risk and local preparedness capability.

- **P** Gather information about hazards, fuel models, risks, threats; use local, state and federal agency information and identify on the base map
- **A** Convene the third CWPP meeting; present and build upon the risk and assessment information; fire chief to "tell it like it is"

Step #6 Establish Community Priorities and Recommendations: Use the base map and community risk assessment to facilitate a collaborative community meeting to identify priority fuel reduction, structural protection, and improved fire response project; clearly indicate relationship to reducing community wildfire risks.

- **P** Develop a process that leads to collaboration and consensus building around the highest priority projects that prevent, mitigate and prepare for risks and hazards; consider wildland fire threat to structures as well as structure to structure fire spread.
- **A** Convene the fourth CWPP meeting; review risk mgmt. and reduction plans; prioritize planning project
- **D** Facilitate the meeting; capture feedback, organize and prioritize; fire chief should be present to encourage and monitor feedback making sure the planning process is staying on track.

Phase 3: Plan, Do and Evaluate

Step #7 Develop an Action Plan and Assessment Strategy: Consider developing a detailed implementation strategy to accompany the CWPP, as well as a monitoring plan that will ensure its long-term success.

- **A** Attain buy in and commitment for the "doing"; track and measure progress; engage private property owners
- **A** Convene the fifth CWPP meeting; fire chief to encourage outcomes and community involvement; fill the gaps and keep the process moving forward
- **D** Set up a method for changing, updating, and revision of the plan; change to meet future demands

Step #8 Finalize Community Wildfire Protection Plan: Communicate CWPP results to the community and key partners.

- **D** Public release and a media blitz about who, what, where, why, and how the fire safe projects are being processed; use planning team members to deliver the message.
- **D** Planning team to develop the background, funding and staffing plans for the projects.
- **A** Leadership team to meet with key stakeholders, property owners, and policy leaders and deliver the plan message; attain signature support from funding agencies.
- **A** Convene the sixth CWPP meeting; celebrate the development of the plan; schedule future meeting to follow implementation, update, funding and tracking of plan; set a specific date for the next meeting.

Step #9 Track Progress and Update CWPP: A plan stays alive when it's evaluated and updated to meet the reality of the implementation days.

- **P** Describe accomplishments to date and review the 8 Step CWPP planning process to pick up loose ends and new areas of concern.
- **A** Convene the seventh CWPP meeting to celebrate success, upgrade existing plans and to plan for the future
- **P** Plan future meetings to track and update the planned activities

UWI STAFF

[Print | Close]

Rich Gray, Regional Fire Coordination/State UWI Coordinator **Bastrop Office** Office: (512) 321 2467 Pager: 1 800 299 4099, ID # 9536 Cell: (979) 218 2406 e-mail: rgray@tfs.tamu.edu	**Traci Weaver, UWI Specialist/Public Information Officer** **Granbury Office** Office: (817) 579 1847 Pager: 1 800 299 4099, ID # 3843 Cell: (979) 218 3035 e-mail: tweaver@tfs.tamu.edu
Robbie Curles, Mitigation/Suppression Specialist **Bastrop Office** Office: (512) 321 2467 Pager: 1 800 299 4099, ID # 4416 Cell: (979) 268 3770 e-mail: rcurles@tfs.tamu.edu	**Jan Fulkerson, UWI Specialist (Neighborhood and Community Planning)** **Wimberly Office** Office: (512) 847 7387 Pager: 1 800 299 4099, ID # 5971 Cell: (979) 200 1010 e-mail: jfulkerson@tfs.tamu.edu
Karen Kilgore, UWI Specialist (GIS and UWI Assessment) **Bastrop Office** Office: (512) 321 2467 Cell: (979) 218 3036 e-mail: kallender@tfs.tamu.edu	**Mary Leathers, UWI Mitigation Exhibit Specialist** **McGregor Office** Office: (254) 840 9086 Pager: 1 800 299 4099, ID # 4925 Cell: (979) 218 3030 e-mail: mleathers@tfs.tamu.edu
Lexi Maxwell, UWI Specialist (Information and Education) **Bastrop Office** Office: (512) 321 2467 Pager: 1 800 299 4099, ID # 0256 Cell: (979) 220 0787 e-mail: lmaxwell@tfs.tamu.edu	**P.J. Pearson, UWI Specialist (Firewise Communities/USA)** **Fredricksburg Office** Office: (830) 997 5426 Pager: 1 800 299 4099, ID # 4419 Cell: (979) 220 1217 e-mail: ppearson@tfs.tamu.edu
Justice Jones, East Texas UWI Coordinator **Conroe Office** Office: (936) 273 2261 Pager: 1 800 299 4099, ID # 1086 Cell: (936) 546 8042 e-mail: jjjones@tfs.tamu.edu	**Lee McNeely, Regional UWI Coordinator** **Linden Office** Office: (903) 665 7400 Pager: 1 800 299 4099, ID # 0064 Cell: (936) 546 315614 e-mail: lmcneely@tfs.tamu.edu

Karen Stafford, Regional UWI Coordinator **Woodville Office** Office: (409) 331 9030 Pager: 1 800 299 4099, ID # 1371 Cell: (936) 545 6991 e-mail: kstafford@tfs.tamu.edu		**Jeff Lester, Regional UWI Coordinator** **Conroe Office** Office: (936) 273 2261 Pager: 1 800 299 4099, ID # 4562 Cell: (936) 544 0964 e-mail: jlester@tfs.tamu.edu
Jan Amen, Public Information Officer **Lufkin Office** Office: (936) 639 8105 Cell: (936) 546 1004 e-mail: jamen@tfs.tamu.edu		**Mahlon Hammetter, Public Information Officer** **Lufkin Office** Office: (936) 639 8162 Cell: (936) 546 1895 e-mail: mhammetter@tfs.tamu.edu

TEXAS FOREST SERVICE
Protecting and sustaining forests, trees and related natural resources

REPORT ARSON OR TIMBER THEFT
1-800-364-3470

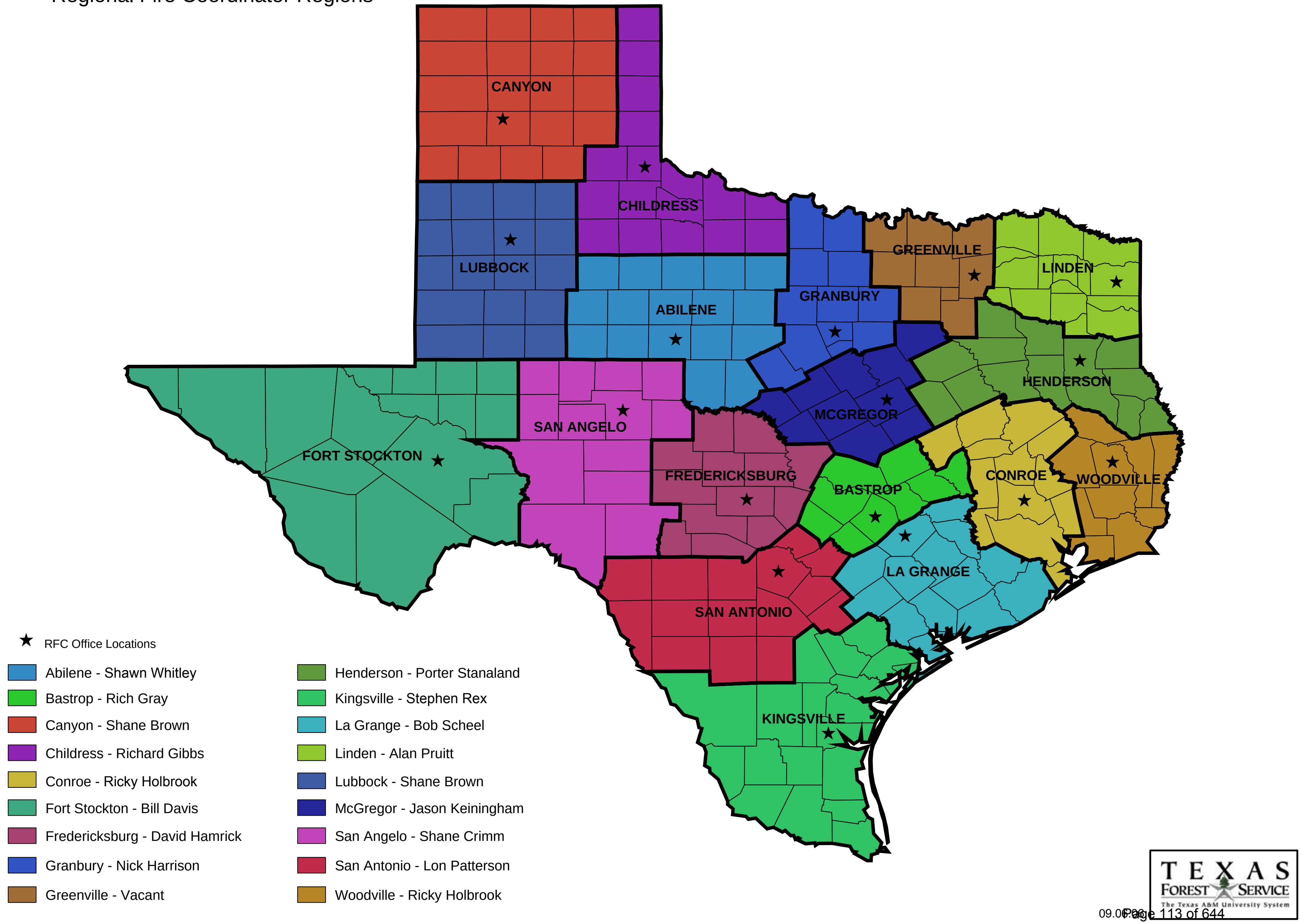
TEXAS REGIONAL FIRE COORDINATORS

[Print | Close]

Texas Regional Fire Coordinators:

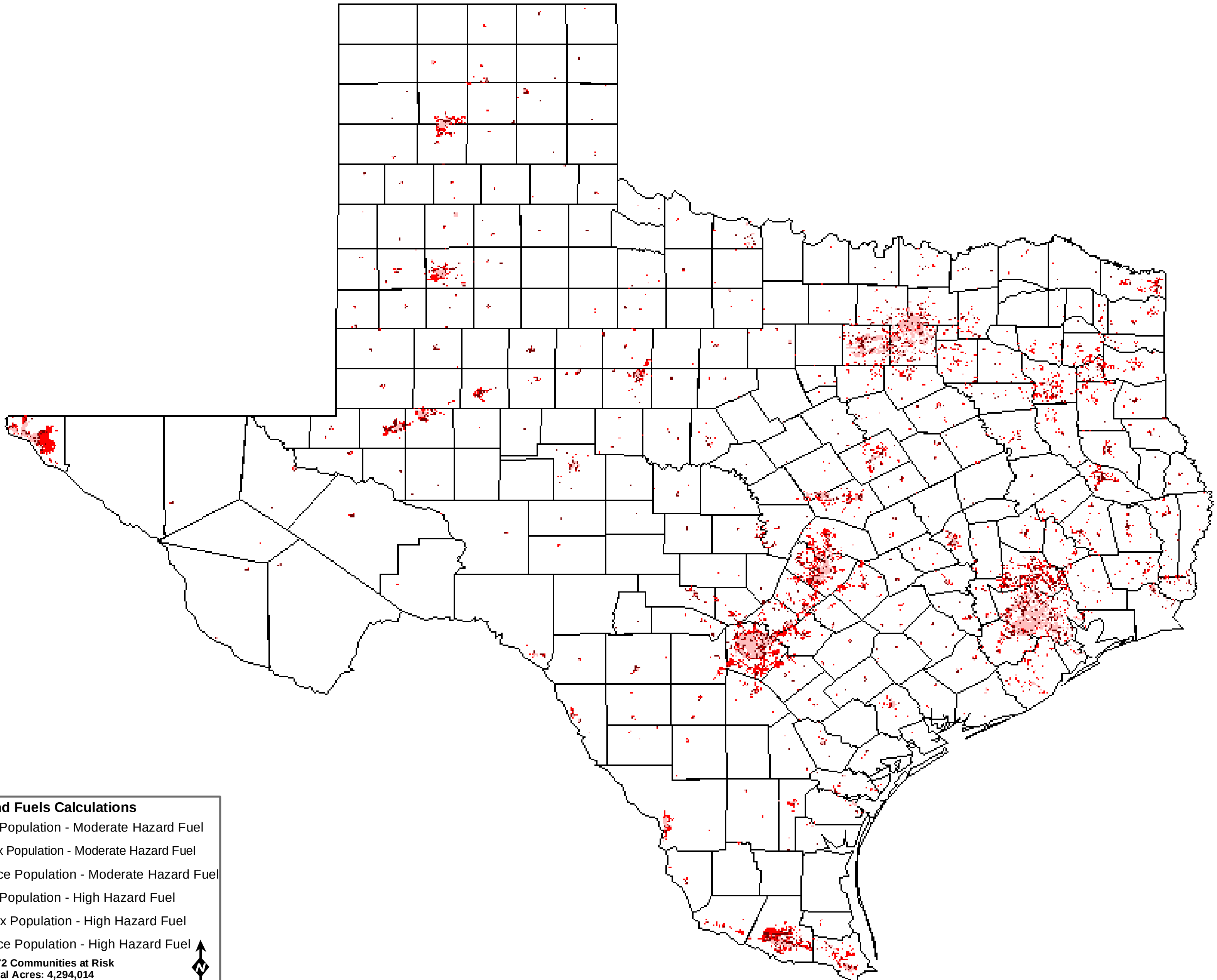
Region	Coordinator	Office Phone	Cell Phone
Abilene	Shawn Whitley	(325) 676 5827	(936) 545 7184
Bastrop	Rich Gray	(512) 321 2467	(979) 218 2406
Canyon	Shane Brown	(806) 651 3473	(979) 220 1540
Childress	Richard Gibbs	(940) 937 2286	(979) 220 0577
Conroe	Ricky Holbrook	(936) 327 4832	(936) 546 3094
Fort Stockton	Bill Davis	(915) 336 7290	(979) 218 2300
Fredericksburg	David Hamrick	(830) 997 5426	(979) 220 0756
Granbury	Nick Harrison	(817) 579 5772	(979) 218 2408
Greenville	vacant		
Henderson	Porter Stanaland	(936) 564 9276	(936) 546 1968
Kingsville	Stephen Rex	(361) 595 5118	(979) 324 0912
La Grange	Bob Scheel	(979) 968 5555	(979) 248 2407
Linden	Alan Pruitt	(903) 734 3504	(936) 546 1915
Lubbock	Shane Brown	(806) 651 3473	(979) 220 1540
McGregor	Jason Keiningham	(254) 840 9086	(979) 218 3108
San Angelo	Shane Crimm	(325) 944 0065	(979) 218 2405
San Antonio	Lon Patterson	(210) 532 5536	(979) 220 0522
Woodville	Ricky Holbrook	(936) 327 4832	(936) 546 3094
West Texas	Paul Hannemann, Chief	(830) 997 5426 (979) 458 7344	(979) 218 2401
West Texas	Les Rogers, Asst. Chief	(325) 676 5827	(979) 218 2403
Central Texas	Marty Martinez, Asst. Chief	(361) 595 5118	(979) 218 2404
East Texas	Bill Rose, Chief	(936) 875 4400 (903) 586 7545	(936) 546 1768

Regional Fire Coordinator Regions



09.06.06

Texas UWI Communities at Risk



Densities and Fuels Calculations

- Urban Population - Moderate Hazard Fuel
- Intermix Population - Moderate Hazard Fuel
- Interface Population - Moderate Hazard Fuel
- Urban Population - High Hazard Fuel
- Intermix Population - High Hazard Fuel
- Interface Population - High Hazard Fuel

1372 Communities at Risk
Total Acres: 4,294,014
Total Square Miles: 6,709.39

N

Using Population Density from Landscan
Intermix was defined as 26-100 people per square kilometer
Interface was defined as 101-500 people per square kilometer
Urban was defined as 500 or more people per square kilometer

TEXAS FOREST SERVICE

Firewise

Produced by UWI Division of Texas Forest Service
K. Kilgore - UWI/GIS Specialist (512) 321-2467

Texas UWI Communities at Risk map is DESCRIPTIVE, not PREDICTIVE.
The map offers a spatial analysis of communities at risk to wildland fires based on population density and fuel types in and around the communities

United States
Department of
Agriculture

Forest Service

Southern Research
Station

General Technical
Report SRS–103

Managing Smoke at the Wildland-Urban Interface

Dale Wade and Hugh Mobley

Authors

Dale Wade, Research Forester (now retired), U.S. Department of Agriculture Forest Service, Southern Research Station, Athens, GA 30602 (www.rxfire@ix.netcom.com); and **Hugh Mobley**, Forester (now retired), U.S. Department of Agriculture Forest Service, Southern Region and Alabama Forestry Commission, Montgomery, AL 30309.

Cover photos: Top by Steven R Miller, Saint John's Water Management District, Palatka, FL. Bottom left by Larry Kohrman, University of Florida. Bottom right courtesy of Dale Wade.

June 2007

Southern Research Station
200 W.T. Weaver Blvd.
Asheville, NC 28804

Managing Smoke at the Wildland-Urban Interface

Dale Wade and Hugh Mobley

Abstract

When prescribed burning is conducted at the wildland-urban interface (WUI), the smoke that is produced can sometimes inconvenience people, but it can also cause more serious health and safety problems. The public is unlikely to continue to tolerate the use of prescribed fire, regardless of the benefits, if burn managers cannot keep smoke out of smoke-sensitive areas. In the South, forest management organizations commonly require that plans for prescribed burns pass a smoke screening review and some States require such a review before they will authorize a burn. Current screening systems, however, do not incorporate criteria for use at the WUI. This guide describes modifications to the Southern Smoke Screening System for burns at the WUI. These modifications couple new research findings with the collective experience of burners who have extensively used the 1976 Southern Smoke Screening System. This new smoke screening system is designed for use on burns less than 50 acres in size and has undergone several years of successful field testing in Florida.

Keywords: Fire management, prescribed fire, smoke management, smoke screening, wildland urban interface.

Contents

List of Figures

List of Tables

Introduction

Periodic prescribed fire is an integral part of the management of fire-adapted ecosystems, where it is a requisite to ecosystem health. At the wildland-urban interface (WUI), it is also used to reduce hazardous fuel accumulations and to produce recreational benefits. Fire managers would like to conduct these burns without alarming nearby residents and without having smoke intrude into smoke-sensitive areas (SSAs), but smoke will likely affect people whenever fire occurs at the WUI. Smoke effects include increased anxiety because a fire is burning nearby, minor nuisances such as ash in swimming pools, temporary inconveniences such as disrupted or detoured traffic flow, and potentially serious public health and safety issues such as aggravation of respiratory aliments and reduction of roadway visibility. Smoke consists of a great many combustion products, some of which are designated as pollutants and, as such, are regulated by various Federal and State statutes (see appendix A). Readers desiring an indepth discussion of air quality regulations and the pollution caused by fire are referred to Hardy and others (2001) and Sandberg and others (2002).

The three general strategies used to manage smoke from prescribed burns, including those at the WUI are: (1) avoid SSAs, (2) disperse and dilute smoke before it reaches SSAs, and (3) reduce production of undesirable combustion products. Managing smoke at the WUI is one of the most difficult tasks a burn manager faces. This is because SSAs are within or adjacent to the burn rather than some distance away. Smoke intrusions into SSAs cause the vast majority of public complaints related to prescribed burning at the WUI. If prescribed fire is to continue to be a viable resource management option, we must make sure the public understands that fire is necessary to perpetuate fire-adapted ecosystems and that attempting to exclude this natural force has untenable long-term consequences. If the public recognizes the dramatically different long-term outcomes between these two fire management strategies, and burn managers demonstrate they can skillfully and safely apply fire, the public is likely to allow the continued use of prescribed fire.

The purpose of this publication is to build upon the knowledge of experienced prescribed burners by describing tools that have proven helpful in reducing smoke problems . For the purposes of this publication we define "experienced" prescribed burners as those who have completed the Florida Interagency Basic Prescribed Fire Course or its equivalent. Users of this guide are encouraged to review the slide presentation for the smoke management unit of that course by going to the Florida Division of Forestry Web site http://www.fl-dof.com/ wildfire/rx_training.html and clicking on "Chapter 6: Smoke Management." Alabama also has an excellent smoke management Web site; to access it, go to www.pfmt.org/fire and click on "Fire Management."

Smoke management basics are briefly reviewed below and tools to help manage smoke at the WUI are discussed. A major modification of the Southern Smoke Screening System is introduced, which can help minimize the likelihood of smoke problems when burning in the WUI. This smoke screening system for use at the WUI has been successfully used for the past 3 years by graduates of an advanced Florida fire management training course. Concepts to keep in mind and important rules for reducing smoke impacts are reviewed in appendix B. A list of suggested reading for those interested in a more detailed treatment of various smoke related topics is provided in appendix C.

Smoke Management Basics

The key to the effective use of prescription fire is to combine appropriate firing techniques and ignition patterns with favorable weather and fuel moisture conditions to produce the desired fire intensity and severity, which will, in turn, achieve the burn objectives. The prescription should, however, also consider offsite effects caused by the byproducts of combustion. Smoke management concerns usually override all other aspects of prescribed fire planning when burning at the WUI because of the proximity of SSAs. The amount of smoke that will be generated by flaming and residual combustion, coupled with the distance to SSAs, will dictate acceptable burning conditions and ignition plans. Manipulation of fuel moisture, wind direction, firing technique, and ignition pattern can usually, but not always, result in an acceptable prescription.

Smoke Production and Significance

The primary components of wildland fire combustion are water vapor and carbon dioxide, especially during the flaming phase when combustion is most efficient. Combustion is much less efficient during the smoldering and residual phases and this inefficiency results in increased particulate emissions (at least double those produced during flaming combustion). Particulate emissions are usually the pollutant of concern in wildland fires because of their impact on visibility and human health. Because most particulates are very small, they:

- Absorb and scatter light which washes out contrast and decreases visibility
- Act as nuclei to facilitate the formation of fog
- Remain suspended in the atmosphere for relatively long periods
- Enter deep into human airways where they exacerbate respiratory problems

The amount of smoke produced is directly related to the amount of fuel consumed; when fuel consumption is doubled, the amount of smoke produced will roughly double, assuming other factors remain constant. Fuel moisture is the most important determinant of the proportion of the total fuel load that will be available during a particular combustion phase. As fuel moisture increases, more heat energy has to be used to convert the moisture to steam; this slows the combustion process and increases smoke production because more of the fuel will be consumed during the residual and smoldering phases. The combustion of damp fuels generates smoke that contains a large amount of water vapor, which, although not a pollutant, has a substantial adverse affect on visibility. Remember that live green fuels and damp fuels, whether live or dead, will significantly increase the amount of moisture in smoke. Burning when fine fuel moisture is fairly low is recommended because less energy is needed to drive off moisture, which means:

- More heat energy is available to preheat additional fuels
- Fuels reach ignition temperature quicker
- More fuel is available
- Combustion efficiency is increased
- Rate of spread and flame length increase resulting in higher fire line intensity
- More of the emissions will be entrained into the smoke plume
- The plume will be lofted higher into the atmosphere

The shape, size, arrangement, stage of decomposition, and chemistry of fuel particles all influence the proportion of the total fuel bed that will be available, as well as combustion efficiency, which in turn influences smoke production. A discussion of fuels can be found on the Florida Division of Forestry prescribed fire training and education Web site at http://www.fl-dof.com/wildfire/rx_training.html. Click on "Chapter 8: Fire Behavior."

Firing Technique

Backing fires have the highest combustion efficiency because the flaming front progresses through the fuel bed relatively slowly, allowing more complete oxidation of the fuel and, thus, fewer intermediate products such as volatile organic hydrocarbons, oxides of nitrogen, and other gaseous emissions of concern. Backing fires generally consume about the same proportion of the forest floor as do heading fires, but in backing fires most of the available fuel is consumed in the flaming front so smoldering after the front has passed is substantially reduced. This significantly decreases the amount of particulate matter generated.

Even though headfires are characterized by incomplete combustion, they still produce only about half as much particulate matter as does smoldering combustion. A typical headfire in southern rough consumes about 60 percent of the available fuel in the flaming phase and 40 percent in the smoldering and residual phases (Southern Forest Fire Laboratory Staff 1976). The bottom line is that headfires produce about three times as much particulate matter as backing fires. Backing fires have two major drawbacks from a smoke management standpoint. Firstly they take more time than other firing techniques to cover a given area, which means smoke will be produced over a longer time period. Secondly, when the distance between upwind and downwind control lines exceeds about 300 feet, less of the area will be burned during the middle of the day when atmospheric dispersion is normally best. For these reasons, the increased intensity of spot fires or a flanking fire is often accepted whenever prudent even though more smoke will be produced, because the smoke will be generated over a shorter time span and be lofted higher into the atmosphere. The only caveat here is that increased fire line intensity may involve more of the understory, which will result in additional emissions. As the age of rough increases, the proportion of the available dead fuel consumed in the flaming front typically decreases; this has important implications when burning at the WUI where fuel loads are usually very high.

Smoke Transport and Dispersion

Explanation of two terms will facilitate discussion of atmospheric stability and its influence over smoke transport and dispersion. Mixing height (MH) is the height to which vigorous mixing due to convection occurs and is a good indicator of the approximate maximum height to which smoke from a low-intensity fire can rise. More intense fires, however, can loft smoke above the mixed layer because it is the temperature of a smoke parcel relative to the environmental temperature that actually determines how high the smoke will rise. As a general rule, do not burn at the WUI unless the MH is at least 1,700 feet. MH becomes less important when very small acreages of short grasses (small quantity of available fuel) are involved, but if the 1,700-foot minimum is violated and a smoke problem occurs, the burner will be held responsible. On the other hand, very intense fires that quickly consume a large amount of fuel can generate enough smoke to exceed the capacity of the air to disperse the smoke efficiently, resulting in reduced visibility at ground level. When burning heavy fuel loads, such as those created when harvesting old-growth stands where much of the material is unmerchantable and thus left on site or by natural events such as high winds or severe pest infestations, increasing the MH will help mitigate potential smoke problems. MH is part of the daily fire weather forecast in many Southern States.

Transport wind velocity (TWV) is another atmospheric parameter given in the daily forecast issued by many State forestry agencies. TWV is the average horizontal wind speed and direction from the surface up to the MH and should be at least 9 miles per hour (mph) when burning is conducted at the WUI. Wind speed is usually greatest in the afternoon and increases with height. This means that as long as surface winds are at least 9 mph, transport winds should be adequate. Keep in mind that it is possible for the wind direction to vary within the mixed layer, so the direction that smoke will be carried depends upon the height that is reached by the plume.

Atmospheric stability indicates how rapidly vertical mixing is taking place in the atmosphere. The more unstable the atmosphere, the quicker and higher the smoke can rise. When burning takes place under marginally unstable conditions, the smoke plume may drop back to ground level miles downwind even though the plume was initially lifted well into the atmosphere by the heat of the fire. Atmospheric instability normally peaks during the afternoon due to solar heating of the Earth's surface and ebbs at night as the surface cools. One can bypass the task of estimating stability on a given day by using the Dispersion Index (DI) developed by Lee Lavdas (Lavdas 1986) which is part of the daily fire weather forecast in many Southern States. This numerical index provides an estimate of the atmosphere's ability to disperse smoke and is conceptually similar to the Ventilation Index but should be a better predictor of smoke dispersion (Lavdas 1986). A doubling of the DI implies a doubling of the atmosphere's capacity to disperse smoke. The DI can be computed for any time period. Daytime and nighttime DI numbers are interpreted differently because different stability classes are used in calculating the estimate. For example, a daytime DI of 40 is the commonly accepted threshold for conducting daytime burns. Nighttime values are, on the other hand, typically very low so a nighttime DI of 12 suggests unusually good dispersion, whereas a daytime value of 12 would be interpreted as poor. Fire managers also want to know the likelihood of reduced nighttime visibility when smoke mixes with higher nighttime relative humidities. Use of the Low Visibility Occurrence Risk Index (LVORI) (Lavdas 1996) in conjunction with the DI provides them with such a predictor. Both of these tools are described below.

A more indepth discussion of meteorological variables that affect emissions can be found by going to the Florida Division of Forestry Web site at http://www.fl-dof.com/wildfire/rx_training.html and clicking on "Chapter 7: Fire Weather." Both Florida and Georgia have full-time fire meteorologists on their forest protection staffs; these meteorologists can answer weather-related questions and, upon request, provide a timely spot weather forecast for your intended burn unit.

Residual Smoke

Smoke produced after the flame front passes is a major concern when burns are conducted at the WUI. Where dead fuel loads are heavy, particularly when a heavy duff layer and/or numerous partially decayed logs are present, smoldering can continue for days, resulting in overstory tree mortality (from root damage) as well as significant smoke problems. This residual smoke remains near the ground where it is moved by eye-level wind flow (not to be confused with 20-foot surface winds). As the ground cools at night, much of this smoke will move down-drainage where it can reduce visibility to near zero at bridges.

Extensive study of archived wind data and field studies conducted by Southern Forest Fire Laboratory staff showed that in Southern States, winds are likely to blow from every direction at some point in time on any given night. For this reason, WUI burn prescriptions usually include more stringent mopup standards, often specifying mopup at least several hundred feet in from all edges.

A guideline used by some fire managers who routinely burn adjacent to homes in Florida is to allow a 12-person crew 12 hours to burn and completely mop up a 5-acre unit in a 5-plus year palmetto/gallberry rough once the prep work has been completed. They have found that for units up to at least 25 acres in size, the total amount of time they spend burning and mopping up will be about the same whether they burn the whole unit in 1 day and come back several days in a row to handle smoke complaints, or whether they break the block into roughly 5-acre blocks and burn and completely mop up one each day with no complaints. Water-and-foam is often the method of choice for mopup at the WUI, and use of smaller burn units facilitates reaching all parts of the burn.

Florida statutes allow authorized fires to actively spread between 0900 and 1 hour before sunset (1 hour after sunset for certified burners), and under certain weather conditions, a burn authorization can be obtained for a nighttime burn. We recommend that all burns at the WUI be started as soon after 0900 as conditions warrant so they can be completed early enough to allow sufficient time for mopup before sunset. Nighttime burns at the WUI should only be considered immediately after passage of a cold front, when the lower ambient temperatures will help minimize overstory crown scorch, and only when the predicted wind velocity will not result in other fire or smoke management concerns.

Tools

Many models and tools have been developed to aid in managing smoke and additional ones are under development. A discussion of available and emerging tools can be found in Sandberg and others (2002) and at http://www.fire.org/. Tools introduced or reviewed in this publication include:

- The DI for assessing the atmosphere's capacity to disperse a smoke plume
- The LVORI for assessing the likelihood of a vehicle accident caused by poor visibility resulting from residual smoke
- A smoke screening system for managing smoke at the WUI

Lavdas Dispersion Index (DI)

The relation of the DI to burning conditions is shown in table 1. The DI is part of the

Table 1—Lavdas Dispersion Index,[a] revised on the basis of extensive use by field practitioners

Lavdas Dispersion Index	Smoke dispersion	Interpretation of daytime values
70 +	Very good	Burning conditions are so good that fires generally present control problems. Reassess decision to burn unless escape, particularly as a result of spotting, is not a problem, e.g., burn unit is surrounded by plowed fields. DI is generally too high for a WUI burn.
50–69	Good	Preferred range for prescription burns, but fire control becomes more difficult as values get higher.
41–49	Generally good	Especially when the planned burn is smaller than 50 acres. Afternoon values in most inland forested areas typically reach this range.
Reassess decision to burn at WUI if daytime DI < 41		
21–40	Fair	Stagnation may be indicated if DI is in this range and windspeed is low. Reassess decision to burn, especially if heavy rough or large dead fuels are present, or unit is larger than 15 acres.
Below 20	Poor to very poor	Do not burn at the WUI.

DI = Dispersion Index; WUI = wildland-urban interface.
[a] Lavdas (1986).

daily fire weather forecast produced by many Southern States.

Low Visibility Occurrence Risk Index (LVORI)

The LVORI (Lavdas 1996) shown in table 2 was developed to rank the relative likelihood of a fog and/or smoke-related accident on the southern Coastal Plain. LVORI is a function of relative humidity and the DI (table 3) based on the proportion of accidents involving fog and/or smoke, as reported by the Florida Highway Patrol from 1979–81. The LVORI is a scale from 1 to 10 with 1 indicating a low likelihood of poor visibility and 10 indicating an extremely high likelihood of poor visibility. The LVORI is a valuable tool for assessing the probability of low visibility in down-drainage areas at night or under stable atmospheric conditions. Caution should be used when contemplating WUI burns with a LVORI of 5 or higher, and WUI burns should not be conducted when the LVORI is predicted to be 7 or higher unless the fire will be completely mopped up (out—no smokes) by dusk.

Southern Smoke Screening Systems

Smoke management at the WUI is one of the most difficult parts of the burn prescription to prepare because SSAs often occur within a short distance on all sides of the intended burn unit. There will not be enough information available in the foreseeable future, nor can a burning prescription integrate all the variables necessary, to predict how much the visibility will be reduced at a given distance from a burn, or the effects it could have on human health and welfare. In fact, many of the interactions between these variables are not yet well understood. Nevertheless, most Southern States have voluntary or mandatory smoke management guidelines that should or must be followed when planning a prescribed fire. Many Southern State forestry agencies have Web sites that provide recommended and/or required procedures. State forestry Web sites can be accessed through the National Association of State Foresters Web site at www.stateforesters.org/.

Table 2—Description of Low Visibility Occurence Risk Index (LVORI) values

LVORI values	Description
1	Lowest proportion of accidents with smoke and/or fog reported (130 of 127,604 accidents, or just over 0.0010 of all accidents)
2	Physical or statistical reasons for not including in LVORI class 1, but proportion of accidents not significantly higher
3	Higher proportion of accidents than LVORI class 1, by about 30 to 50 percent, marginal significance (between 1 and 5 percent)
4	Proportion of accidents significantly higher than LVORI class 1 (by a factor of about 2)
5	Proportion of accidents significantly higher than LVORI class 1 (by a factor of 3 to 10)
6	Proportion of accidents significantly higher than LVORI class 1 (by a factor of 10 to 20)
7	Proportion of accidents significantly higher than LVORI class 1 (by a factor of 20 to 40)
8	Proportion of accidents significantly higher than LVORI class 1 (by a factor of 40 to 75)
9	Proportion of accidents significantly higher than LVORI class 1 (by a factor of 75 to 125)
10	Proportion of accidents significantly higher than LVORI class 1 (by a factor of about 150)

Table 3—Low Visibility Occurrence Risk Index (stable conditions such as at night)

Relative humidity	Dispersion Index										
	> 40	40–31	30–26	25–17	16–13	12–11	10–9	8–7	6–5	4–3	2	1
< 55	1	1	2	2	2	2	2	2	2	2	2	2
55–59	1	1	2	2	2	2	2	3	3	3	3	3
60–64	1	1	2	2	2	2	3	3	3	3	3	3
65–69	1	3	3	3	3	3	3	3	3	3	3	4
70–74	3	3	3	3	3	3	3	3	3	3	3	4
75–79	3	3	3	3	4	4	4	4	4	4	4	4
80–82	3	3	3	3	4	4	4	4	4	5	5	6
83–85	4	4	4	4	4	4	4	4	5	5	5	6
86–88	4	4	4	4	4	5	5	5	5	6	6	6
89–91	4	4	4	4	5	5	5	5	6	6	7	7
92–94	4	4	4	5	5	5	6	6	6	6	7	8
95–97	4	4	4	5	5	6	6	6	7	8	8	9
> 97	4	4	4	5	5	7	8	8	9	9	10	10

Few WUI prescribed fire projects can pass any smoke screening system now in use, but prescribed burning is necessary to perpetuate fire-dependent plant communities in the WUI. For this reason, the Southern Smoke Screening System (Southern Forest Fire Laboratory Staff 1976) has been modified to facilitate successful smoke management when burning is conducted at the WUI. The new system, the WUI Smoke Screening System, is described herein. It is based largely on extensive fieldwork conducted by Hugh Mobley, which he used to modify the original version of the Southern Forestry Smoke Management Guide. (To see the guide as modified by Mobley, go to www.pfmt.org/fire, click on "Fire Management," then click on "Smoke Management.") Dale Wade further modified the Southern Forestry Smoke Management Guide; the resulting WUI Smoke Screening System is intended specifically for WUI burns smaller than 50 acres.

For larger units, the original screening system found in The Southern Forestry Smoke Management Guidebook (Southern Forest Fire Laboratory Staff 1976) should be used. It can be found on the Web at http://www.srs. us.usda. gov/pubs/viewpub.jsp?index=683. If the intended burn does not pass that system, consider breaking it into smaller units and using the WUI Smoke Screening System.

The latter system is straightforward and is designed for use in the initial planning phase as part of the written burn prescription. It should also be used just before the burn to suggest alternatives when weather conditions are not as described in the plan. This system should not be used without a working knowledge of fire behavior and smoke management. The better one's understanding of the factors that affect smoke, the more fully and safely one will be able to interpret the results provided by this WUI screening system. Both smoke screening systems utilize many, but not all, of the major variables that affect smoke. Values are based on "worst average" weather and fuel conditions and worst case events. In some cases, indices are based on very limited research and field verification. The total amount and rate at which smoke will be produced are crucial elements in developing a burn prescription, but are at best only indirectly addressed in current smoke screening systems (including this one). For example, the effects of fuel loading by size class, fuel moisture, and fuel compaction on smoke production have only been studied on a very coarse scale. Therefore, current smoke screening systems can only suggest whether a smoke problem is likely, marginally likely, or not likely. They are a starting place to get a feel for managing smoke.

The burn manager must make the final decision. Experience and knowledge must be coupled with familiarity with the locale so the burn manager can judge whether the burn in question is likely to cause a smoke intrusion given the weather conditions and firing techniques spelled out in the burn prescription. The more experienced and knowledgeable that person is about prescription fire and smoke management, the better the decision will be.

Smoke and Nighttime Burns

As a general rule, nighttime burns should not be conducted in the WUI. The nighttime atmosphere is usually stable, surface winds are near calm and the direction of light breezes is generally variable and difficult to predict, fine fuel moisture content is higher, and inversions are common. More combustion products, particularly water vapor, are thus produced and plume rise is limited, so the smoke tends to remain much closer to the ground where it reduces visibility, especially when combined with fog. Nonetheless, nighttime burns are sometimes advocated, e.g., in young pine stands because ambient temperature tends to be lower at night. If such a situation arises at the WUI, a nighttime burn should only be considered when the weather forecast predicts steady winds lasting all night. Such conditions are usually associated with passage of a cold front. The fire and smoke should be monitored continuously and a tractor-plow unit should be onsite so that the burn can be terminated if necessary. Have lighted "smoke" signs available and make sure local law enforcement personnel are alerted. A nighttime DI forecast can be obtained in Florida, Georgia, and several other Southern States. Interpretation of nighttime DI is entirely different from interpretation of daytime DI. At night a value of 8 or higher is generally acceptable (in selected rural areas of Florida, a nighttime DI value of 3 is permissible). Note that the WUI Smoke Screening System detailed below is *not* applicable for nighttime burns.

Gaining Experience in Smoke Management

To increase your understanding of how much smoke is produced and what happens to it in various plant communities under different weather and topographic conditions we suggest the following:

- Observe—Observe and document the production, transport, and dispersion of smoke on prescribed burns, even when no SSAs are identified. Check downwind and down-drainage to observe the smoke during the day, at dusk, before midnight, and at dawn the next morning. Document the distance to which the smoke is a visibility problem. Include all the above information in your written burn evaluation. This information can be used later when burns are conducted in the same fuel type under the same general conditions and you have SSAs to consider.
- At dusk—Always check your burn for smoke at dusk. If there is residual smoke, monitor all night unless there is very little, in which case, check again just before daylight the next morning.
- Fog-prone areas—Learn where and at what time fog generally occurs in your area. Locate and mark fog-prone areas on your administrative map.

When developing a burn prescription, check to see if the smoke plume might reach a fog-prone area. If the plume will likely reach such an area, make sure photos are taken to document the burn and smoke dispersion. If fog forms in the potential impact area the evening after a burn, monitor all roads in the area throughout the night. Be aware that conditions can deteriorate from relatively good visibility to zero visibility within a matter of minutes. Consider developing a smoke patrol plan with thresholds for specified levels of activation; Bill Twomey developed such a plan for the Francis Marion National Forest in South Carolina in the 1990s and has found it very useful.

The WUI Smoke Screening System includes estimates of minimum distances that burns should be from SSAs to minimize the impacts of smoke on these SSAs. Because data are limited, the WUI Smoke Screening System tends to be conservative. For example, prescribed burns may be smaller in size, or for some other reason produce less smoke than the system suggests. If you take the time to record and catalog the smoke results of your WUI burns, this accumulating data will allow better estimation of potential impacts of smoke on SSAs in your area.

If following any of the guidelines in the WUI Smoke Screening System results in smoke intrusion into an SSA, mitigate the intrusion and then *please* do all the following:

- Estimate the downwind extent of the problem
- Try to determine the exact cause of the problem
- Think about how you can adjust the screening system so it will not happen again
- Notify others of the problem you encountered, e.g., your local fire council, and get word back to Scott Goodrick with the Southern Research Station, Disturbance Work Unit, Smoke Management Team located in Athens, GA (http://www.srs.fs.fed. us/smoke)

The Wildland-Urban Interface Smoke Screening System

This system has five steps. Figure 1 diagrams the process.

- Step 1—Plot distance and direction of probable smoke plume and residual smoke
- Step 2—Identify SSAs
- Step 3—Deal with SSAs within the first one-fourth of the downwind and down-drainage impact distance
- Step 4—Deal with SSAs within the last three-fourths of the downwind and down-drainage impact distance
- Step 5—Interpret screening system results

Step 1—Plot Distance and Direction of Probable Smoke Plume

Step 1A

Use a map on which the locations of all SSAs can be identified and plot the footprint of the planned burn. Then draw another line around the burn 500 feet out from the edge of the burn area. This 500-foot buffer zone indicates the minimum area that is likely to be impacted regardless of wind direction. If the intended burn unit is larger than 50 acres, divide it into subunits that are less than 50 acres in size. Go to step 1B.

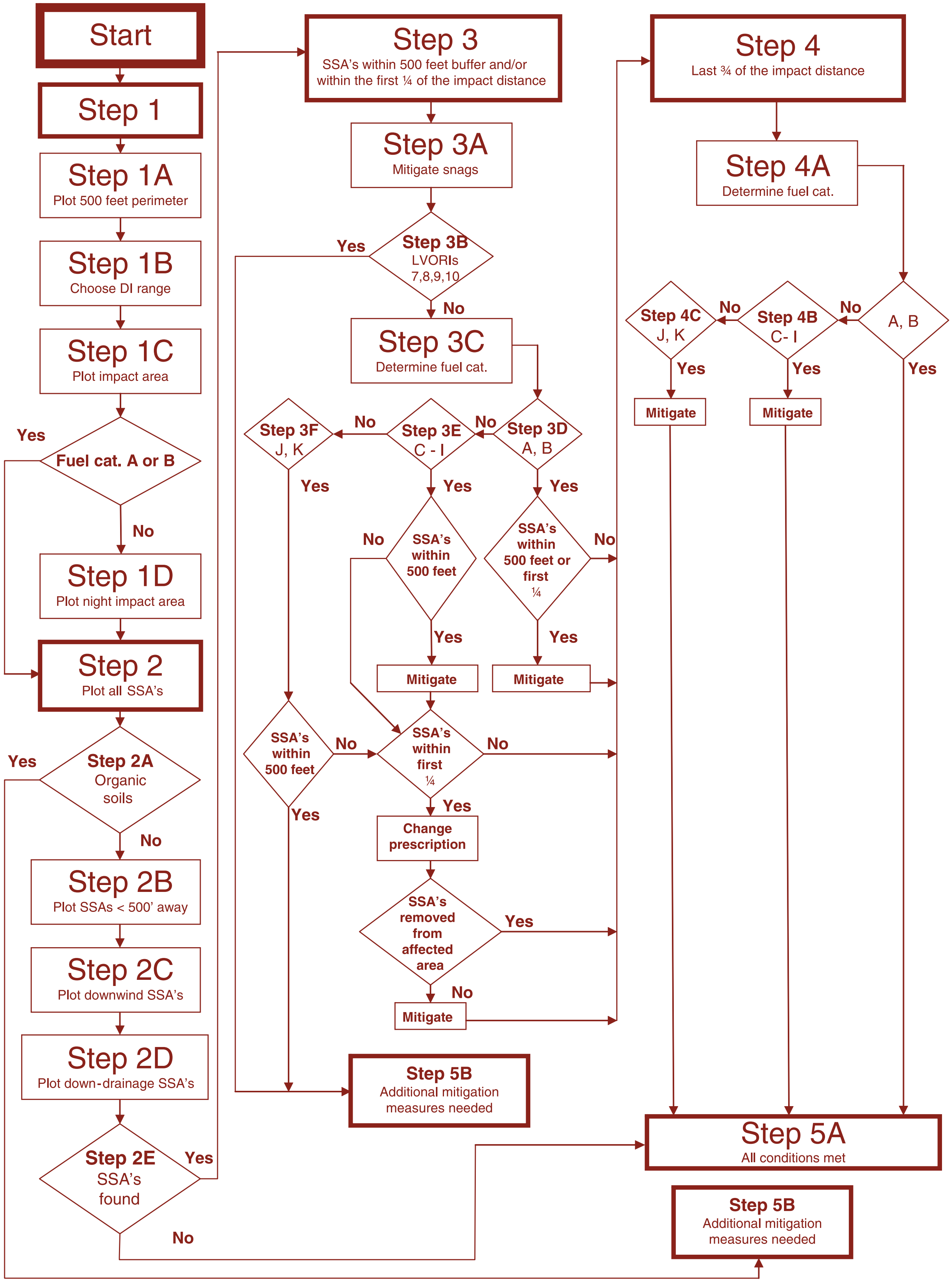


Figure 1—Flowchart of the Wildland-Urban Interface Smoke Screening System.

Step 1B

Choose the DI under which you plan to burn. Lower DIs (< 41) are not recommended because of poor smoke dispersion and DIs above 70 are not recommended because of the likelihood of fire control problems. Note that in Florida, the DI threshold for red-flag conditions is 75. Consider the DI chosen to be a tentative selection at this point. Go to Table 4 and use the tentatively selected DI to determine the maximum distance to which smoke is likely to be a problem based on the fuel category and firing technique chosen. Visible smoke may be present for this distance, although smoke can be smelled at much greater distances. Go to step 1C.

Table 4—Greatest distance of probable smoke impact from burns smaller than 50 acres

Fuel category		Firing technique	Dispersion Index 41–50	51–60	61–70
			Impact distance in miles		
A	Grass, light understory (< 2-year rough) with no humus layer	Any firing technique	0.75	0.5	0.25
B	Nonwoody marsh fuels—rush, cattail, or sawgrass	Any firing technique	1.5	1.25	1
C	Palmetto/gallberry or waxmyrtle understory regardless of height	Backing fire	1.25	1	0.75
D[a b]	Palmetto/gallberry or waxmyrtle understory regardless of height	Head, flank, or spot fires	4	3	2
E	Any other native understory fuel type regardless of height	Backing fire	1	0.75	0.5
F	Any other native understory fuel type under 3 feet high	Head, flank, or spot fires	1.5	1	0.75
G	Any other native understory fuel type over 3 feet high	Head, flank. or spot fires	2	1.5	1
H[a b]	Melaleuca	Backing, flank, or spot fires	3	2	1
I	Exotic fuelbeds such as Casuarina without much understory	Any firing technique	2.5	2	1.5
J[a]	Scattered logging debris	Any firing technique	2.5	1.5	1
K[a]	Small dry piles	Any firing technique	3	2	1.5
L[c]	Large, wet, piled debris or windrows	Using any firing technique	Do not burn		

[a] Firing should be completed at least 2 hours before sunset because dispersion will rapidly deteriorate at dusk.
[b] Line headfires in 4- to 5-foot high palmetto, gallberry, waxmyrtle, or Melaleuca are very likely to result in severe overstory crown scorch.
[c] Windrows are the most polluting of all southern fuel types. They contain large fuels and dirt, and are compact which makes them very slow to dry and severely limits the amount of oxygen available for the combustion process. Dirt in piles or windrows will drastically increase the amount of smoke produced, and debris piles containing substantial amounts of dirt can smolder for weeks. To pass this screening system, any large piles of debris or windrows will have to be reconfigured into small round piles and allowed to dry with stumps removed or fireproofed.

Step 1C

Draw a line representing the centerline of the planned path of the smoke plume (transport wind direction) from the burn. Draw this line for the length of the impact distance determined from table 4. To allow for horizontal dispersion of smoke as well as shifts in wind direction, draw two additional lines out the same distance from the burn unit at 30-degree angles from the centerline of the transport wind direction. Connect the ends of the lines with arcs as in figures 2 and 3. Note that the transport wind direction and surface wind direction may differ on the day of the burn, e.g., if a seabreeze is present. In this case, plan for the change in smoke plume direction. When burning on a seabreeze, keep in mind that once the smoke plume is over water, it will likely drop to the surface and be blown back inland; the firing technique and pattern used should, thus, assure that the plume has dissipated by the time it might be blown back across the shoreline so that people will not be adversely impacted. When rechecking winds on the day of the burn, if forecast or actual surface winds are light (< 5 mph), replot the impact area using 45-degree angles.

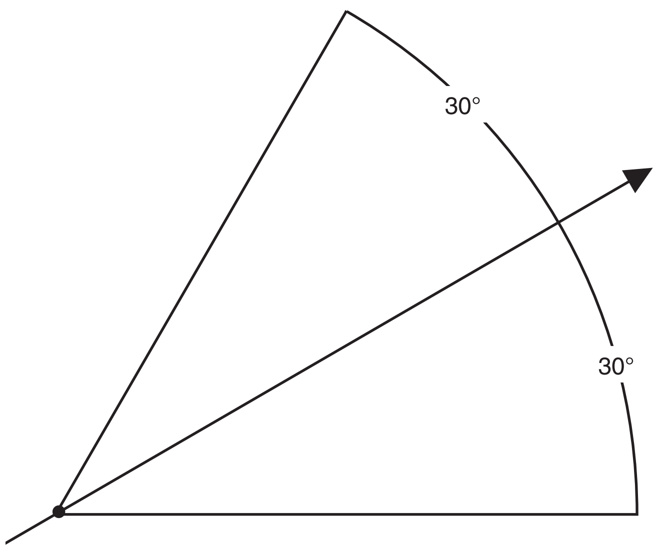


Figure 2— Plot of the probable smoke impact area when a point represents the burn.

If the planned burn is represented as a spot on the map you are using, draw as in figure 2 with a protractor and straight edge. If the map scale allows the burn dimensions to be drawn on the

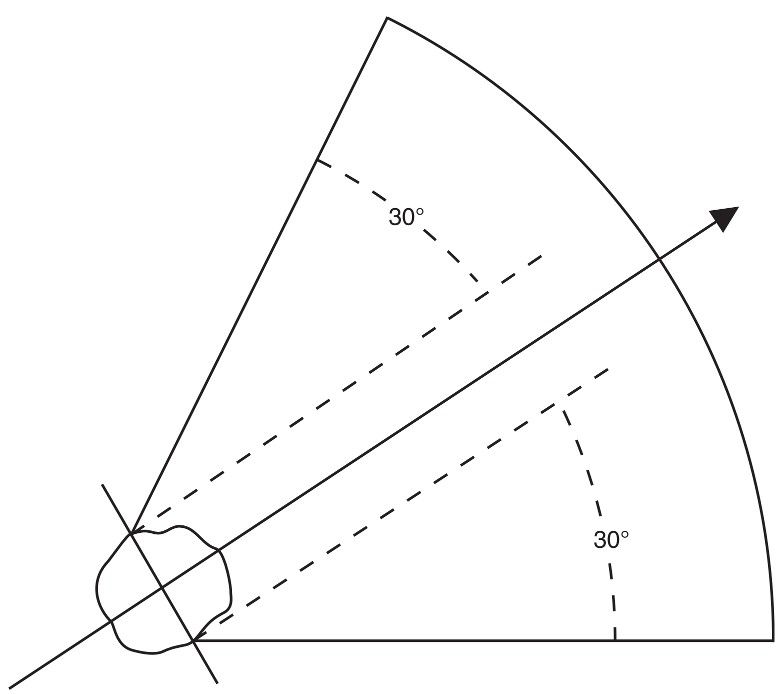


Figure 3— Plot of the probable smoke impact area when a figure other than a point represents the burn.

map, do so and draw as in figure 3. The result is the probable daytime smoke impact area. The heaviest smoke concentration will be along the centerline.

Figure 4 shows the application of step 1C to an example area. If the fuels present are grass, nonwoody marsh fuels, or less than a 2-year rough (fuel categories A and B), go to step 2, otherwise go to step 1D.

Step 1D

Next, go down-drainage the same distance determined from table 4 in step 1B. Draw a narrow area covering only the "bottom" or width of the drainage area. This area may or may not lie wholly within the daytime smoke impact area. The result is your probable nighttime impact area due to the residual (smoldering) smoke produced. Note that the probable down-drainage nighttime smoke impact area shown in figure 4 can extend further than the distance suggested in table 4 because the smoke will be concentrated within this relatively narrow area and will seek the lowest elevation. If the smoke encounters heavy vegetation in the drainage, it will build up at that point. If an open area such as a pasture or field is also adjacent to the drainage at that point, the smoke will tend to spill over into this area if the terrain is fairly level.

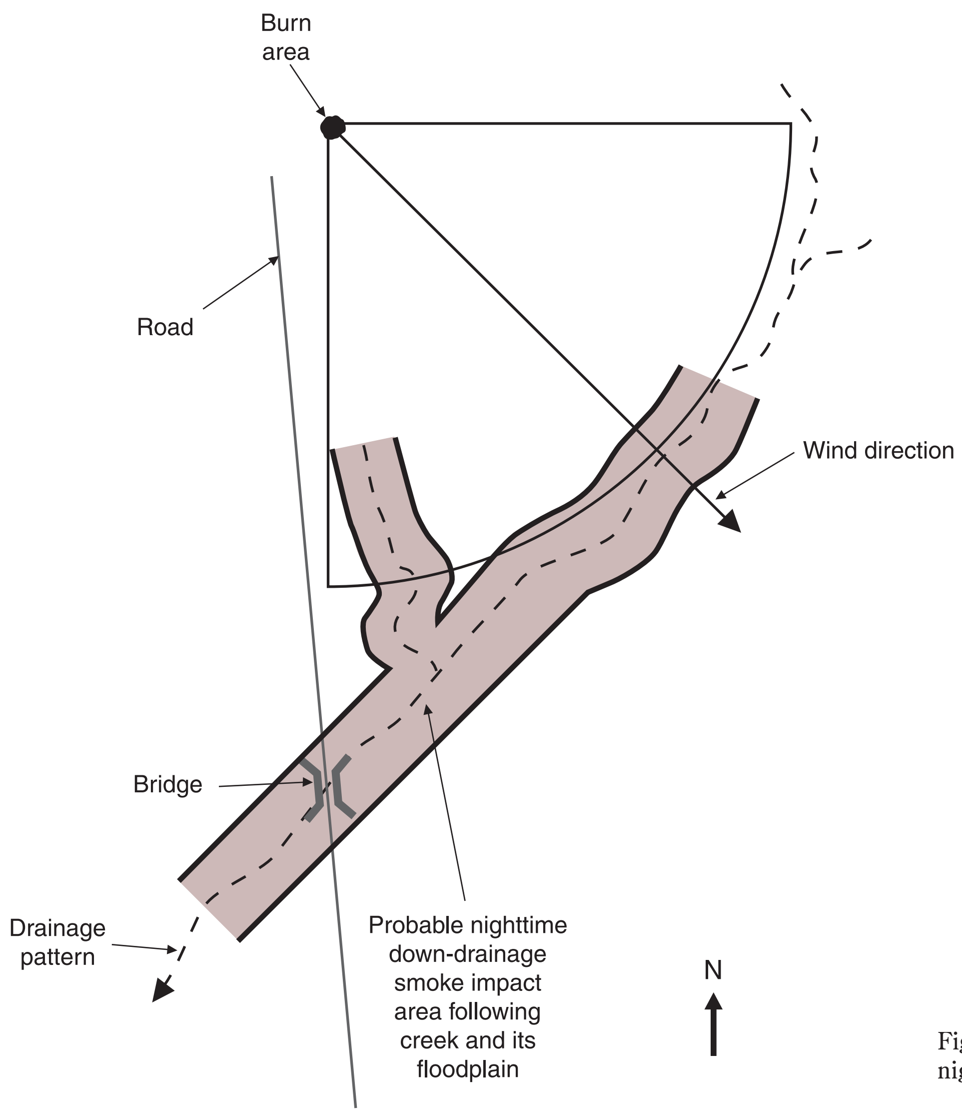


Figure 4— Plot of probable nighttime smoke impact area.

If your preburn site inspection suggests this could happen, monitor that area for smoke buildup after the burn, especially if an SSA is near the other end of the open area. Complete step 1D even if you plan to have the burn completely mopped up (out) at least 2 hours before dusk. Then, if for some reason residual smoke is present at dusk, you will know where it is likely to concentrate. Go to step 2.

Step 2—Identify Smoke Sensitive Areas

Step 2A

If the area to be burned contains organic soils that are likely to ignite, go to step 5B, otherwise go to step 2B.

Step 2B

Identify and mark any SSAs within 500 feet of the perimeter of the planned burn, regardless of direction from the fire as determined in step 1A above. Add these to the contact list in your written prescription. Make sure these SSAs are also discussed in the public relations section of your prescription. Go to step 2C.

Step 2C

Identify and list any SSAs located within the probable downwind impact area determined in step 1C. Go to step 2D.

Step 2D

Identify and list any SSAs located within the down-drainage impact area determined in step 1D. Go to step 2E.

Step 2E

If any SSAs were identified in 2B through 2D, mitigation is necessary as suggested in steps 3 and 4. Go to step 3.

If no SSAs are found, as described in steps 2A through 2D, then it is not likely you will have a smoke management problem. Go to step 5A.

Step 3—Dealing with Smoke Sensitive Areas within the 500-foot Buffer and/or First One-Fourth of the Impact Distance

Step 3A

Consider felling snags. If their retention is spelled out in the land management plan, follow standard procedures to keep them from igniting. Go to step 3B.

Step 3B

If the predicted or actual LVORI is 7, 8, 9, or 10, go to step 5B.

Step 3C

For fuel categories A through I: If any homes are within the 500-foot buffer, each homeowner must be personally contacted and informed that his or her home will likely be impacted by smoke. The landowner responses, e.g., that there are severe respiratory problems or fears that homes will be lost, should guide what actions are taken (include in the public relations plan).

Use the same fuel category selected in step 1B (table 4). Fuel category selections follow:

- Fuel category A or B: Go to step 3D
- Fuel category C, D, E, F, G, H, or I: Go to step 3E
- Fuel category J or K: Go to step 3F

Step 3D—Fuel Categories A and B

If no SSAs are within the 500-foot buffer zone or first one-fourth of the downwind smoke impact distance, go to step 4.

If any SSAs are within the buffer zone or first one-fourth of the predicted downwind smoke impact distance, a smoke problem resulting from the burn is a distinct possibility. First, try changing the prescribed wind direction or increasing the prescribed DI to minimize the number of SSAs that are within the smoke impact area.

If changing the wind direction or increasing the DI removes all SSAs from the buffer and first one-fourth of the downwind smoke impact distance, go to step 4. Otherwise, it is unavoidable that an SSA will be within the buffer zone or first one-fourth of the impact distance and mitigation will be necessary. Either mop up the burn completely (all smokes out) at least 1 hour before sunset or complete active burning at least 3 hours before sunset under one or more of the conditions listed below and mop up until dark:

- DI above 50
- MH above 2,500 feet
- Surface winds < 8 mph and transport wind speeds > 15 mph
- If the SSA is a road, mitigate by controlling or rerouting traffic during the burn

Continue by going to step 4.

Step 3E—Fuel Category C, D, E, F, G, H, or I

If an SSA is within 500 feet of the fire perimeter, regardless of the direction from the fire, divide the unit into two or more subunits, the smaller of which faces the SSA. An exception to creation of subunits can occur where smoke corridors are already established by county ordinance.

- The smaller subunit should have a depth such that the distance from the closest SSA to the back of the subunit is at least 500 feet on the edge of the burn facing the SSA. This edge should be delineated with a hard (plowed or raked) line or drainage ditch containing standing water. The burn manager may select a shorter distance in some specific situations, but much caution should be used. If the SSA is a road, closing the road during the burn removes this distance restriction. If the SSAs are homes, all homeowners must agree to the reduced distance with the full understanding that their residences could be impacted by drift smoke. In some uncommon situations, a Federal or State statute such as the Hawkins Law in Florida may allow you to ignore these guidelines, but we urge you to first carefully consider the potential public relations ramifications of such a decision.
- Burn this smaller subunit first toward the middle of the day, preferably when steady eye-level winds are blowing away from the SSA at speeds > 2 mph. If you desire to burn this subunit when eye-level winds are blowing toward the SSAs, consider specifying weather conditions and a firing technique that will facilitate lofting the smoke plume over the SSAs.
- If an SSA is down-drainage, make sure the subunit can be burned and completely mopped up (out) by dusk. This may require breaking the subunit into smaller (about 5-acre) blocks.
- If the SSA is a road, mitigate either by rerouting traffic during the burn or by stationing flaggers strategically. Be ready to extinguish the fire if necessary.

Once the smaller subunit is burned out, if no other SSAs are within 500 feet of the burn, address any SSAs within the first one-fourth of the impact area.

When multiple SSAs are within 500 feet of the burn unit on more than one side, your options are further constrained. If roads are present, control traffic flow; if homes are present, contact all residents and make sure they understand that their residences may be impacted by residual smoke. As a general rule, a residence should not be directly impacted by the plume, or impacted by residual smoke throughout the night. If you are not sure that *all* smoke will be pulled away from the SSAs as the remaining subunits are burned, divide the remaining subunits further.

If no SSAs are within the first one-fourth of the downwind smoke impact distance, go to step 4.

If any SSAs are within the first one-fourth of the downwind smoke impact distance, a smoke problem resulting from the burn is a distinct possibility. Change prescribed wind direction or increase DI to minimize the number of SSAs that lie within the first one-fourth of the downwind smoke impact distance.

If changing the prescribed wind direction or increasing the DI removes all SSAs from the first one-fourth of the downwind smoke impact distance impact area, go to step 4. If one or more SSAs remain within the first one-fourth of the impact distance, you must mitigate the problem. Burn and mop up completely (all smokes out) at least 1 hour before sunset, or complete active burning at least 3 hours (2 hours if using a backfire as described in the fourth bullet below) before sunset under one or more of the conditions listed below and mop up until dusk.

- DI above 50
- Divide unit into roughly 5-acre blocks and burn them separately
- Surface winds < 8 mph and transport wind speeds above 15 mph
- Use a backing fire and complete burn at least 2 hours before sunset. Begin mopup as soon as practicable after the flame front has passed.
- MH above 2,500 feet
- Keep stumps from igniting
- If the SSA is a road, mitigate by controlling or rerouting traffic during the burn

Continue by going to step 4.

Step 3F—Fuel Categories J and K

If any SSAs are within the 500-foot buffer zone, go to step 5B.

If no SSAs are within the first one-fourth of the downwind smoke impact distance, go to step 4.

If any SSAs are within the first one-fourth of the downwind smoke impact distance, a smoke problem resulting from the burn is a distinct possibility. Change prescribed wind direction or increase DI to minimize the number of SSAs that lie within the first one-fourth of the downwind smoke impact distance.

If changing the prescribed wind direction or increasing the DI removes all SSAs from the first one-fourth of the downwind smoke impact distance, go to step 4. If an SSA is unavoidable within the first one-fourth of the impact distance, you must mitigate the problem. Burn and mop up completely (all smokes out) at least 1 hour before sunset. The following conditions will facilitate smoke dispersal:

- DI above 50
- Keep stumps from igniting
- Divide the unit into roughly 5-acre blocks and burn these subunits separately
- Burn when the MH is above 2,500 feet
- Surface winds < 8 mph and transport wind speeds > 15 mph
- If the SSA is a road, control or reroute traffic during the burn

Continue by going to step 4.

Step 4—Dealing with Smoke Sensitive Areas within the Last Three-Fourths of the Impact Distance

Step 4A

Select the same fuel category used in step 3. Selections are grouped by fuel category as follows:

- Fuel category A or B: Go to step 5A

- Fuel category C, D, E, F, G, H, or I: Go to step 4B
- Fuel category J or K: Go to step 4C

Step 4B—Fuel Category C, D, E, F, G, H, or I

Either:

- Complete firing at least 3 hours before sunset and mop up a minimum of 500 feet in from the downwind edge of the burned area, or
- Use a backing fire and completely mop up the burn at least 1 hour before sunset. Begin mopup soon after the flame front has passed and continue until dusk

If residual smoke is present at dusk, monitor all night and be prepared to act if a roadway is impacted.

Continue by going to step 5A.

Step 4C—Fuel Category J or K

If no interstate or major highways are within 2 miles down-drainage, consider the list of potential measures below. Implement as many as practical to mitigate potential smoke problems.

- Burn when the DI is above 50
- Reduce the size of the area to be burned
- Complete firing at least 3 hours before sunset
- Mop up as needed
- Burn when surface winds are < 8 mph and transport wind speeds are > 15 mph
- Monitor smoke all night and be prepared to act if a roadway is impacted
- Keep stumps from igniting
- Burn when MH is above 2,500 feet

If interstate or other major highways are within 2 miles down-drainage, divide the unit into subunits and implement as many of the above measures as practical.

Continue by going to step 5A.

Step 5—Interpreting Screening System Results

Step 5A—All Requirements Met

If all the requirements in the smoke screening system have been met to this point, it is not likely that the prescribed fire will result in a smoke problem if the maximum burn unit size is < 50 acres. Keep in mind that as the DI class under which the burn is conducted increases, fire intensity and suppression become more challenging. In order to use this WUI screening system for burn units > 50 acres, you must subdivide the unit into blocks of 50 acres or less to conform with the underlying assumptions used in developing this system.

If you proceed and a smoke problem is encountered, please notify others of the problem you encountered, e.g., your prescribed fire council, and get word back to Scott Goodrick with the Southern Research Station, Disturbance Work Unit, Smoke Management Team located in Athens, GA, at the following Web address: http://www.srs.fs.fed.us/smoke/contacts.htm so that the situation can be examined and changes to the screening system can be made as appropriate.

Step 5B—Not All Requirements Met

If not all smoke screening system requirements have been met, consider the following options:

- Do not burn. Use a mechanical, chemical, or biotic alternative instead
- Change the prescription to meet the requirements
- Reduce the burn unit size to roughly 2-acre blocks, burn with low surface winds, and mop up completely by dark

There may be rare situations where a proposed burn will not pass any smoke screening system under the best dispersion conditions, but the use of fire is still the preferred alternative (e.g., see

Miller and Wade 2003). In such cases, the burn manager should take all the extra steps listed below and then proceed with extreme caution:

- All homeowners within the potential impact area agree to tolerate any temporary inconveniences associated with the intended burn [unless burning within a legalized smoke corridor or under a state statute such as the Hawkins Law (Florida Statute 590.125)]
- Local law enforcement and government officials are kept informed and agree with the necessity of the burn
- All homeowners are contacted within several weeks of the burn and informed of the planned burn date, anticipated ignition time, burn duration, and mopup time. Homeowners should be given the address of a Web site where any schedule changes will be posted
- In the above situations, it is still recommended that:
  - Photos be taken before, during and after the fire including any residual smoke indicating time of photo.
  - The burn be completely mopped up and declared out before burn personnel leave
  - If residual smoke is present at dusk, monitor it throughout the night

If some conditions are marginal, smoke could still be a problem; consider reducing the size of the burn. On the other hand, it may be possible to burn without causing a smoke intrusion even though this screening system indicates otherwise. Situations where this is likely the case include:

- The distance to the SSA is close to the maximum impact distance
- The amount of available fuel is less than average
- The fuel is very dry and the fuel bed is loosely arranged
- The only downwind SSA is close to the end of the arc constructed in step 1C. Note that the heaviest smoke concentration will be along the centerline

The decision to proceed with the burn or to delay it until another time is up to the manager of the prescribed burn. Remember that ideal conditions at ignition time can change during the burn. This will most likely happen to every prescribed fire manager as a result of conditions that are not anticipated or not as forecasted. When such a situation occurs, follow three guiding principles:

1. Use common sense—Do what a prudent individual would do
2. Use integrity—Do the right thing
3. Keep good records—Have and follow a written plan and document all changes to it as they are made

Hot Tip

This smoke screening system does not take into account other sources of smoke that may already be reducing visibility in the area.

Minimum background visibility around the intended burn site should be at least 5 miles.

Acknowledgments

This screening system is based on the screening system developed by the Southern Forest Fire Laboratory Staff (1976) and revisions to it as dictated by extensive field use over the next several decades which can be accessed at www.pfmt.org/fire, a Web site maintained by Auburn University. The lead author modified this revised product at the request of the Florida Division of Forestry to develop a smoke management unit to be taught at an advanced training course for certified prescribed burners. Development of this course entitled “Implementing Prescribed Fire in the Wildland Urban Interface” was facilitated by Don Carlton with the Washington Institute. The first draft of this unit was critically reviewed by the course faculty and suggested modifications hammered out in discussion with faculty members, notably Jim Brenner, Barry Coulliette, Rich Gordon, John Kern, and Judy Turner with the Florida Division of Forestry; Steven Miller with the St. Johns Water Management District; Caroline Noble with the National Park Service; and Walt Thomson with The Nature Conservancy. Don Carlton produced original electronic versions of figures 1 and 4. This and all other evolving units were then presented in a dry run to a group of hand picked experienced burners and further modified in light of their comments. In February 2003, the smoke unit was distributed to the faculty and participants of the dry run as well as to remaining Florida Division of Forestry Forest Area Supervisors and Prescribed Burn Team Leaders; these people were asked to use and evaluate the screening system. Based on the positive feedback from those who used and evaluated this screening system over the next 2 years and the lack of any reported problems, it was decided to formalize and publish this WUI screening system for use throughout the South. The authors also wish to thank Jim Brenner with the Florida Division of Forestry, Scott Goodrick with the USDA Forest Service, and Paul Watts with the South Carolina Forestry Commission who reviewed this manuscript and made valuable contributions. Rick Henion with the Maine Forest Service produced clip art used in this report.

Literature Cited

Hardy, C.C.; Ottmar, R.D.; Peterson, J.L. [and others], comps., eds. 2001. Smoke management guide for prescribed burning and wildland fire: 2001 edition. PMS 420–2. Boise, ID: National Wildfire Coordinating Group. 226 p.

Lavdas, L.G. 1986. An atmospheric dispersion index for prescribed burning. Research Pap. SE–256. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 33 p.

Lavdas, L.G. 1996. Improving control of smoke from prescribed fire using low visibility occurrence risk index. Southern Journal of Applied Forestry. 20(1): 10-14.

Miller, S.R.; Wade, D. 2003. Re-introducing fire at the urban/wild-land interface: planning for success. Forestry. 76 (2): 253-260.

Sandberg, D.V.; Ottmar, R.D.; Peterson, J.L.; Core, J. 2002. Wildland fire in ecosystems: effects of fire on air. Gen. Tech. Rep. RMRS–GTR–42. Ogden, UT: U.S. Department of Agriculture Forest Service, Rocky Mountain Research Station. 79 p. Vol. 5.

Southern Forest Fire Laboratory Staff. 1976. Southern forestry smoke management guidebook. Gen. Tech. Rep. SE–10. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station. 140 p. Available on the Web at: http://www.srs.fs.usda.gov/pubs/viewpub.jsp?index=683. [Date accessed: March 2007].

Appendix A

Some Federal and Florida Air Quality Laws and Rules

Federal Clean Air Act

- The Clean Air Act (as amended in 1987 and 1997) is a legal system designed to protect human health and welfare.
- Several sections of the Clean Air Act have smoke management implications.
- The Clean Air Act establishes minimum requirements, which must be met nationwide, but States may establish additional requirements.
- The various acts, amendments, and regulations can be found on the U.S. Environmental Protection Agency (EPA) Web site at http://www.epa.gov/epahome/laws.htm.

National Ambient Air Quality Standards

- EPA has established National Ambient Air Quality Standards (NAAQS) for the following air pollutants that are produced in wildland fires:
  - Particulate matter
  - Nitrogen dioxide
  - Ozone
  - Carbon monoxide
- Air quality monitors are located throughout Florida and maintained by the Florida Department of Environmental Protection, Division of Air Quality
- These monitors are often located at the wildland-urban interface, so they are much more likely to be impacted by smoke at levels exceeding the NAAQS

Florida Statutes and Rules Pertaining to Smoke Management

- Burn authorization is required from Florida Division of Forestry.
- Florida Division of Forestry may restrict or cancel authorizations if burning under rule 5I–2 of the Florida Administrative Code creates a condition that is deleterious to health, safety, or general welfare.

continued

Appendix A (continued)

Florida Statutes and Rules Pertaining to Smoke Management (continued)

- Florida Division of Forestry authorizations require burning to be done between 9 a.m. and 1 hour before sunset or at other times when conditions warrant. For certified burners, this time period is extended to 1 hour after sunset.
- Smoke from a burn must not reduce visibility on public roadways to < 500 feet.
- A burn must not violate local laws, rules, regulations, or ordinances.
- An updated synopsis of current Florida statutes and rules governing fire management can be found on the Florida Division of Forestry wildland fire Web site at http://www.fl-dof.com/wildfire/index.

Appendix B

How to Reduce the Smoke Impact from Prescribed Burns

Prescribed burning can be used to achieve many resource objectives, but it pollutes the air. Burn managers have an obligation to minimize this pollution. If this obligation is ignored, prescribed burners can be held liable for smoke-related damage if smoke causes accidents or other problems. To reduce the impact of smoke at the wildland-urban interface (WUI), heed the following advice:

1. Smoke management should be based on common sense and integrity.
2. Prepare a written burn plan well in advance of the burn.
3. Define objectives. Be sure you have clear resource objectives and have considered both onsite and offsite environmental impacts.
4. Develop a smoke management plan and attach it (along with any calculations) to the written burn prescription.
5. Fire weather and smoke management forecasts are available through State forestry agencies. Be sure to use them. Such information is necessary to predict smoke production and movement as well as fire behavior. If the forestry weather outlook does not agree reasonably well with the radio or television forecast, find out why before proceeding.
6. In States that have a forestry agency fire meteorologist, such as Florida and Georgia, consider asking for a spot weather forecast. Contact information can be obtained by calling your local forestry unit.
7. Don't burn during pollution alerts or stagnant conditions. Smoke tends to stay near the ground at such times, will not disperse readily, and will exacerbate existing conditions. Many fire weather meteorologists include pollution alerts and stagnation information in their daily forecasts. The mixing height should be at least 1,700 feet and transport windspeed should be at least 9 miles per hour (mph) when prescribed burns are conducted.
8. Comply with air pollution control regulations. Know the regulations that apply at the proposed burn site when you write the prescription. Check with your State fire control agency if in doubt.
9. Burn when conditions are good for rapid dispersion. Ideally, the atmosphere should be slightly unstable so smoke will rise and dissipate, but not so unstable as to cause a control problem. Again, your local forestry agency can help. Some States use category day based on the ventilation rate to describe smoke transport and dispersion conditions, but the Dispersion Index (DI) is a better indicator.
10. Reassess a decision to burn at the WUI when the daytime DI is forecast to be below 41 and use increasing caution as it approaches 70.
11. Use caution when within 500 feet of smoke-sensitive areas (SSAs) or upwind of them. Burning should be done when wind will carry smoke away from public roads, airports, hospitals, schools, and

continued

Appendix B (continued)

How to Reduce the Smoke Impact from Prescribed Burns (continued)

populated areas. This is often not possible at the WUI so extreme care must be exercised to minimize the impact on SSAs. Do not burn if a hospital, school (in session), or airport (unless departures and arrivals can be temporarily suspended) is within one-half mile downwind of the proposed burn.

12. Work with local law enforcement personnel to manage or reroute traffic on downwind roads. Avoid heavy traffic periods such as noontime and late afternoon. Monitor for residual smoke on roads within 1 mile of the burn in all directions until the fire is declared out.

13. Develop and implement a public relations plan that includes personal contact with all homeowners and businesses within one-half mile of the burn unit. Check for any health issues, especially respiratory problems, and schedule the burn when any residents with relevent health problems will be gone overnight; work with such residents to find a place to stay or consider paying to put them in a motel at least the first night postburn. Use firing techniques and ignition patterns that minimize offsite fly ash, make sure windows in all houses likely to be impacted are closed on the day of the burn. Make sure inside pets are removed during the burn. Make sure all potentially affected residents understand that prescribed fire reduces the hazardous accumulation of fuels as well as air pollution from wildfires.

14. When burn units have adjacent SSAs on three or more sides or when they are down-drainage, try to keep burn units smaller than 5 acres so they can be burned and completely mopped up within a single day. It is much better to divide a 20-acre block into four 5-acre blocks and burn and mop up each on a separate day than to burn all 20 acres as a single unit and impact adjacent homes over the next several days until mopup is complete.

15. If the unit has homes on all sides (no smoke corridor), do not burn when DI is < 41. The larger the area being burned, the greater the amount of particulate matter put into the air, and the longer visibility is reduced downwind. However, if weather conditions are good for rapid smoke dispersion, as when the DI is above 50, it is often better from a smoke management standpoint to burn the whole area at one time using a firing technique that creates a convection column to loft the smoke over nearby structures and roads. Remember that creation of a convection column during the flaming phase does little to mitigate production, dilution, or dispersion of residual smoke.

16. Fine fuels carry a fire. Removal of large (100- and 1000-hr) dead, down fuels will have little effect on reducing the fire hazard at the WUI. Once they are ignited, however, large fuels generate smoke for extended periods. Choose burning conditions that will minimize ignition of

Appendix B (continued)

How to Reduce the Smoke Impact from Prescribed Burns (continued)

large fuels. Ideally, burn when they are wet and fine fuels are dry. Headfires are less likely to ignite larger fuels because they have a shorter residence time. If large fuels present are sound, consider the practicability of physically removing them prior to the burn.

17. Check moisture content of fine fuels and lower litter by feeling with your hands. Upper litter should be fairly dry and lower litter too wet to burn.
18. Use the Keetch-Byram Drought Index (also called the Cumulative Severity Index). If large-diameter fuels are present, reconsider a decision to burn when it is above 400 or use a moisture meter to make sure the moisture content of large dead fuels is above 20 percent.
19. If snags or stumps are present, take measures to keep them from igniting.
20. Use a test fire to confirm smoke behavior. Set it in or adjacent to (if fuel conditions are comparable) the area proposed for burning, away from roads or other edge effects, and make sure it is large enough for you to assess smoke behavior.
21. Consider using a backfire at least near homes. Although slower and more expensive, a backing fire produces less smoke (only about one-third of the particulate emissions generated by a heading fire). Substantially less smoldering combustion takes place in backing fires, and smoldering combustion emits about five times as much particulate matter as flaming combustion emits.
22. Burn during the middle of the day when possible. Atmospheric conditions are generally most favorable for smoke dispersion at this time.
23. Do *not* ignite organic soils. If they are present at the WUI, use another method to reduce hazardous fuel accumulations. The only exception is if the organic soil is confined to depressional ponds, in which case burn only when they are full (no organic soil above water). It is virtually impossible to put out an organic soil fire without submerging it in water. It will smoke for weeks despite control efforts, creating severe smoke problems for miles around. Such fires can also re-ignite unconsumed surface fuels days or weeks later, resulting in a wildfire.
24. As a rule of thumb, do not burn at the WUI after sunset because smoke drift is almost impossible to predict when surface winds die down. One exception is the night after a frontal passage when surface winds will be above 4 mph and relative humidity will stay below 70 percent.
25. *Never* burn at the WUI under an inversion, no matter how small the unit.
26. A nighttime smoke patrol is recommended when a burn at the WUI is still smoking at sundown.
27. Anticipate down-drainage smoke flow. Atmospheric conditions tend to become

continued

Appendix B (continued)

How to Reduce the Smoke Impact from Prescribed Burns (continued)

stable at night. Stable conditions tend to keep smoke near the ground. In addition, downslope winds generally prevail at night even on gradual slopes unless surface winds are stronger. Thus, smoke will flow down-drainage and concentrate in low areas. When relative humidity rises above 80 percent and smoke is present, the formation of fog becomes increasingly likely as moisture condenses on the smoke particles. There are few satisfactory solutions to these problems, so try to avoid burning at the WUI late in the day.

28. Start mopup soon after the flame front passes to reduce the impact on visibility. Use water, ideally with foam, to extinguish duff around tree stems, and all stumps, snags, and logs.
29. Have an emergency plan. Be prepared to extinguish a prescribed burn if it is not burning according to plan, or if weather conditions change. Have warning signs on site. If wind direction changes, be prepared to quickly direct traffic on affected roads until traffic control personnel arrive.

Appendix C

Suggested Reading

Achtemeier, G.L. 2001. Simulating nocturnal smoke movement. Fire Management Today. 61: 28-33.

Battye, R.; Bauer, B.; MacDonald, G. 1999. Features of prescribed fire and smoke management rules for Western and Southern States. Chapel Hill, NC: EC/R Inc. Contract 68–D–98–026. Prepared for: U.S. Environmental Protection Agency

Breyfogle, S.; Ferguson, S.A. 1996. User assessment of smoke dispersion models for wildland biomass burning. Gen. Tech. Rep. PNW–GTR–379. Portland, OR: U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 30 p.

Bryan, D.C., ed. 1997. Conference proceedings: environmental regulation & prescribed fire: legal and social challenges. Tallahassee, FL: Florida State University, Center for Professional Development. 246 p.

Eshee, W.D. 1997. Legal implications of using prescribed fire. In: Environmental regulation & prescribed fire: legal and social challenges. Tallahassee, FL: Florida State University, Center for Professional Development: 126-130.

Harms, M.F.; Lavdas, L.G. 1997. Draft user's guide to VSMOKE–GIS for workstations. Research Pap. SRS–6. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 41 p.

Lavdas, L.G. 1996. Program VSMOKE – user manual. Gen. Tech. Rep. SRS–6. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 147 p.

Lavdas, L.G; Hauck, C.A. 1991. Climatology of selected prescribed fire highway safety parameters for Florida. In: Proceedings, 11th conference on fire and forest meteorology. SAF Publ. 91–04. Bethesda, MD: Society of American Foresters: 564-571.

Laverty, L.; Williams, J. 2000. Protecting people and sustaining resources in fire-adapted ecosystems: a cohesive strategy. Washington, DC: U.S. Department of Agriculture Forest Service. 85 p.

Malm, W.C. 2000. Introduction to visibility. CA–2350–97. Ft. Collins, CO: Colorado State University, Cooperative Institute for Research in the Atmosphere: T097-04, T098-06.

Mobley, H.E. 1989. Summary of smoke-related accidents in the South from prescribed fire (1979–1988). Tech. Release 90–R–11. American Pulpwood Association.

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

U.S. Department of the Interior; U.S. Department of Agriculture; U.S. Department of Energy [and others]. 2001. Review and update of the 1995 Federal wildland fire management policy. Boise, ID: Bureau of Land Management. 78 p.

continued

Appendix C (continued)

Suggested Reading (continued)

U.S. Environmental Protection Agency. 1998. Interim air quality policy on wildland and prescribed fires. [Place of publication unknown]: U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. 29 p.

U.S. Environmental Protection Agency. 2000. National ambient air quality standards (NAAQS). http://www.epa.gov/air/criteria.html. [Date accessed: March 2007].

U.S. Environmental Protection Agency. 2000. Wildland fire issues group. http://www.epa.gov/ttncaaa1/faca/fa08.html. [Date accessed: March 2007].

Wade, D.D.; Lunsford, J.D. 1989. A guide for prescribed fire in southern forests. Tech. Publ. R8–TP11. Atlanta: U.S. Department of Agriculture Forest Service, Southern Region. 56 p. [Reprinted by National Wildfire Coordinating Group. Available from National Interagency Fire Center, Boise, ID.]

Wade, Dale and Mobley, Hugh, 2007. Managing smoke at the wildland-urban interface, Gen. Tech. Rep. SRS-103. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 28 p.

When prescribed burning is conducted at the wildland-urban interface (WUI), the smoke that is produced can sometimes inconvenience people, but it can also cause more serious health and safety problems. The public is unlikely to continue to tolerate the use of prescribed fire, regardless of the benefits, if burn managers cannot keep smoke out of smoke-sensitive areas. In the South, forest management organizations commonly require that plans for prescribed burns pass a smoke screening review and some States require such a review before they will authorize a burn. Current screening systems, however, do not incorporate criteria for use at the WUI. This guide describes modifications to the Southern Smoke Screening System for burns at the WUI. These modifications couple new research findings with the collective experience of burners who have extensively used the 1976 Southern Smoke Screening System. This new smoke screening system is designed for use on burns less than 50 acres in size and has undergone several years of successful field testing in Florida.

Keywords: Fire management, prescribed fire, smoke management, smoke screening, wildland urban interface.

The Forest Service, United States Department of Agriculture (USDA), is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

The USDA prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD).

To file a complaint of discrimination, write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410, or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity provider and employer.

A Publication of the

National Wildfire Coordination Group

Sponsored by

United States
Department of Agriculture

United States
Department of the Interior

National Association of
State Foresters

SMOKE MANAGEMENT GUIDE FOR PRESCRIBED AND WILDLAND FIRE 2001 Edition

PMS 420-2
NFES 1279

December 2001

SMOKE MANAGEMENT GUIDE FOR PRESCRIBED AND WILDLAND FIRE
2001 Edition

EDITORS/COMPILERS:
Colin C. Hardy
Roger D. Ottmar
Janice L. Peterson
John E. Core
Paula Seamon

PRODUCED BY:
National Wildfire Coordinating Group
Fire Use Working Team

Additional copies of this publication may be ordered by mail/fax from:
National Interagency Fire Center, ATTN: Great Basin Cache Supply Office
3833 S. Development Avenue
Boise, Idaho 83705. Fax: 208-387-5573.
Order NFES 1279

An electronic copy of this document is available at http://www.nwcg.gov.

Forward

The National Wildfire Coordinating Group's (NWCG) Fire Use Working Team[1] has assumed overall responsibility for sponsoring the development and production of this revised Smoke Management Guide for Prescribed and Wildland Fire (the "Guide"). The Mission Statement for the Fire Use Working Team includes the need to coordinate and advocate the use of fire to achieve management objectives, and to promote a greater understanding of the role of fire and its effects. The Fire Use Working Team recognizes that the ignition of wildland fuels by land managers, or the use of wildland fires ignited by natural causes to achieve specific management objectives is receiving continued emphasis from fire management specialists, land managers, environmental groups, politicians and the general public. Yet, at the same time that fire use programs are increasing, concerns are being expressed regarding associated "costs" such as smoke management problems. This revised Guide is the Fire Use Working Team's contribution to a better national understanding and application of smoke management.

Bill Leenhouts—Chair
NWCG Fire Use Working Team

[1] The NWCG website [http://www.nwcg.gov] contains documentation and descriptions for all NWCG working teams.

Preface

The National Wildfire Coordinating Group's Fire Use Working Team sponsored this 2001 edition of the *Smoke Management Guide for Prescribed and Wildland Fire*. A six-member steering committee was responsible for development of a general outline and for coordination of the Guide's production. The editors/compilers invited the individual contributions, edited submissions, authored many of the sections, obtained comprehensive reviews from the NWCG agencies and other partners, and compiled the final material into a cohesive guidebook.

Steering Committee: **Bill Leenhouts** (chair, NWCG Fire Use Working Team), **Colin C. Hardy**, **Roger D. Ottmar**, **Janice L. Peterson**, **John E. Core**, **Paula Seamon**.

Authors:

Gary Achtemeier, *Research Meteorologist*, USDA Forest Service, Southern Research Station. Athens, GA

James D. Brenner, *Fire Management Administrator,* State of Florida Dept. of Agriculture and Consumer Service, Division of Forestry, Tallahassee, FL

John E. Core, *Consultant*, Core Environmental Consulting. Portland, OR

Sue A. Ferguson, *Research Atmospheric Scientist*, USDA Forest Service, Pacific Northwest Research Station. Seattle, WA

Colin C. Hardy, *Research Forester* USDA Forest Service, Rocky Mountain Research Station. Missoula, MT

Sharon M. Hermann, *Research Ecologist*, Department of Biological Sciences, Auburn University. Auburn, AL

Bill Jackson, *Air Resource Specialist*, USDA Forest Service, Region 8, Asheville, NC

Peter Lahm, *Air Resource Program Manager*, USDA Forest Service, Arizona National Forests. Phoenix, AZ

Bill Leenhouts, *Fire Ecologist*, USDI Fish and Wildlife Service, National Interagency Fire Center. Boise, ID

Tom Leuschen, *Owner—Fire Vision*, USDA Forest Service, Okanagon National Forest. Okanagon, WA

Robert E. Mutch, *Consultant Forester*, Systems for Environmental Management. Missoula, MT

Roger D. Ottmar, *Research Forester*, USDA Forest Service, Pacific Northwest Research Station. Seattle, WA

Janice L. Peterson, *Air Resource Specialist*, USDA Forest Service, Mt. Baker-Snoqualmie National Forest. Mountlake Terrace, WA

Timothy R. Reinhardt, *Industrial Hygienist*, URS Corp. Bellevue, WA

Paula Seamon, *Fire Management Coordinator*, The Nature Conservancy, Fire Management Program. Tallahassee, FL

Dale Wade, *Research Forester*, USDA Forest Service, Southern Research Station. Athens, GA

Table of Contents

Chapter 1

INTRODUCTION

Introduction

Colin C. Hardy

Bill Leenhouts

Why Do We Need A National Smoke Management Guide?

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

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

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

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

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

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

Guide Goals and Considerations

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

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

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

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

Overview and Organization of the Guide

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

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

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

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

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

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

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

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

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

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

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

History of Smoke Management Guidance

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

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

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

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

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

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

The 2001 Edition of the Smoke Management Guide

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

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

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

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

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

Literature Citations

NWCG. 1985. Prescribed fire smoke management guide. NWCG publication PMS-420-2. Boise, ID. National Wildfire Coordinating Group. 28 p.

Southern Forest Fire Laboratory Staff. 1976. Southern forestry smoke management guidebook. USDA For. Serv. Gen. Tech. Rep. SE-10. Asheville, N.C. USDA Forest Service, Southeast Forest Experiment Station. 140 p.

USDA Forest Service. 1978. Effects of fire on air. USDA For. Serv. Gen. Tech. Rep. WO-9. Washington, D.C. USDA Forest Service. 40 p.

Chapter 2

OVERVIEW

The Wildland Fire Imperative

Colin C. Hardy

Sharon M. Hermann

Robert E. Mutch

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

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

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

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

Fire in Wildlands

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

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

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

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

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

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

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

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

Ecological Effects of Altered Fire Regimes

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

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

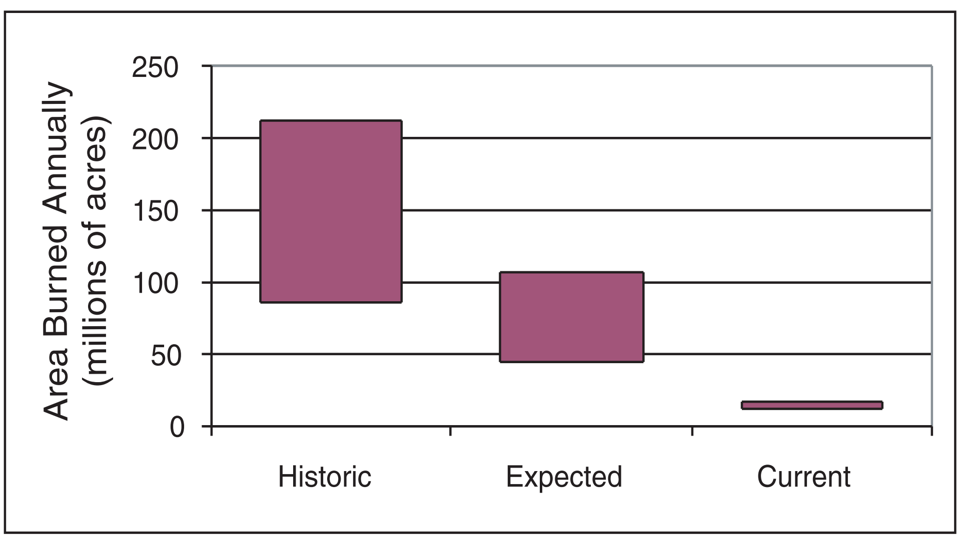


Figure 2.2. Estimates of the range of annual area burned in the conterminous United States pre-European settlement (Historic), applying presettlement fire frequencies to present land cover types (Expected), and burning (wildland and agriculture) that has occurred during the recent past (Current). Source: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

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

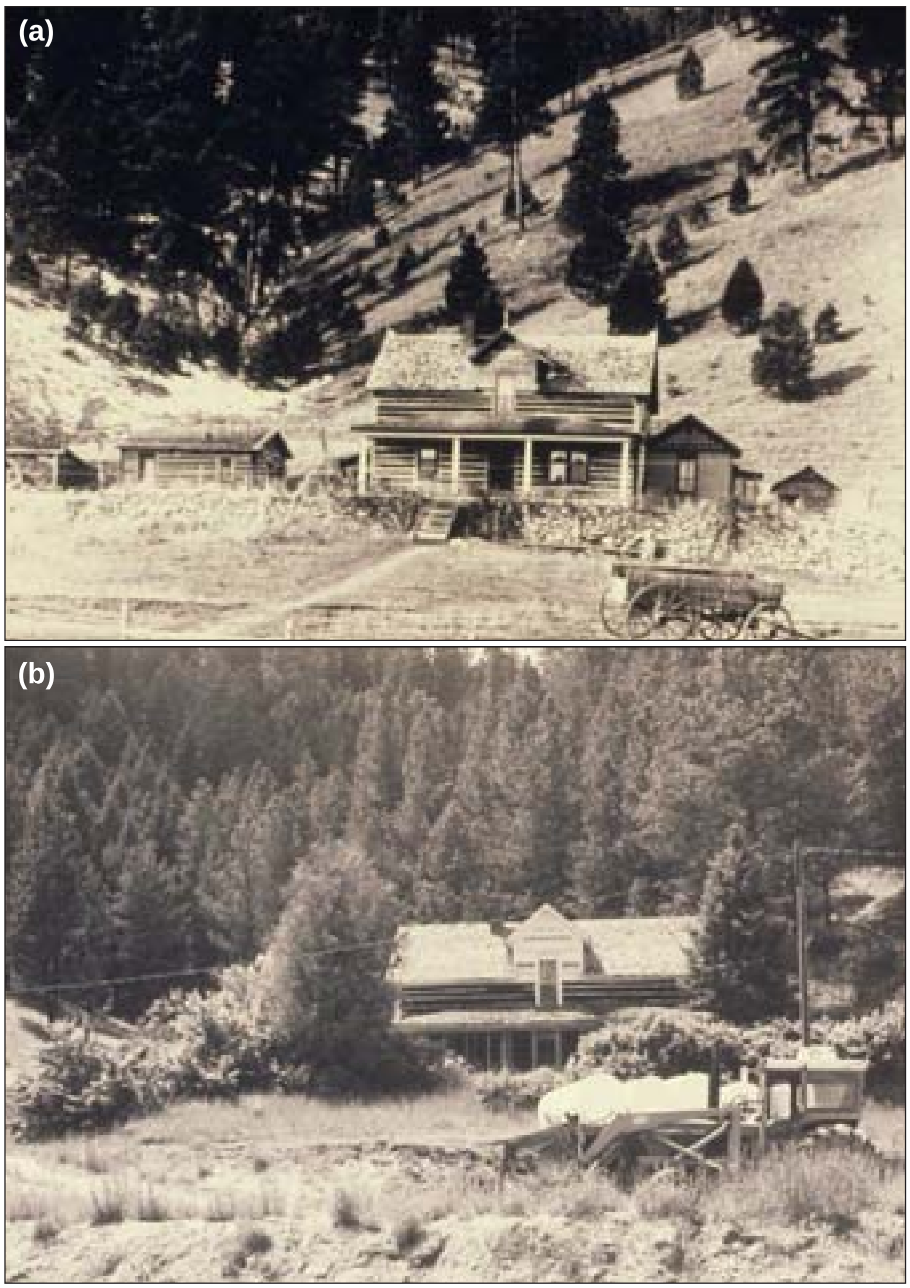


Figure 2.3. These two photos, taken of the same homestead near Sula, Montana, show 85 years of change on a fire-dependent site where fire has been excluded. The top photo (a) was taken in 1895. By 1980 (b), encroaching trees and shrubs occupy nearly all of the site. Stand-replacing crown fire visited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

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

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

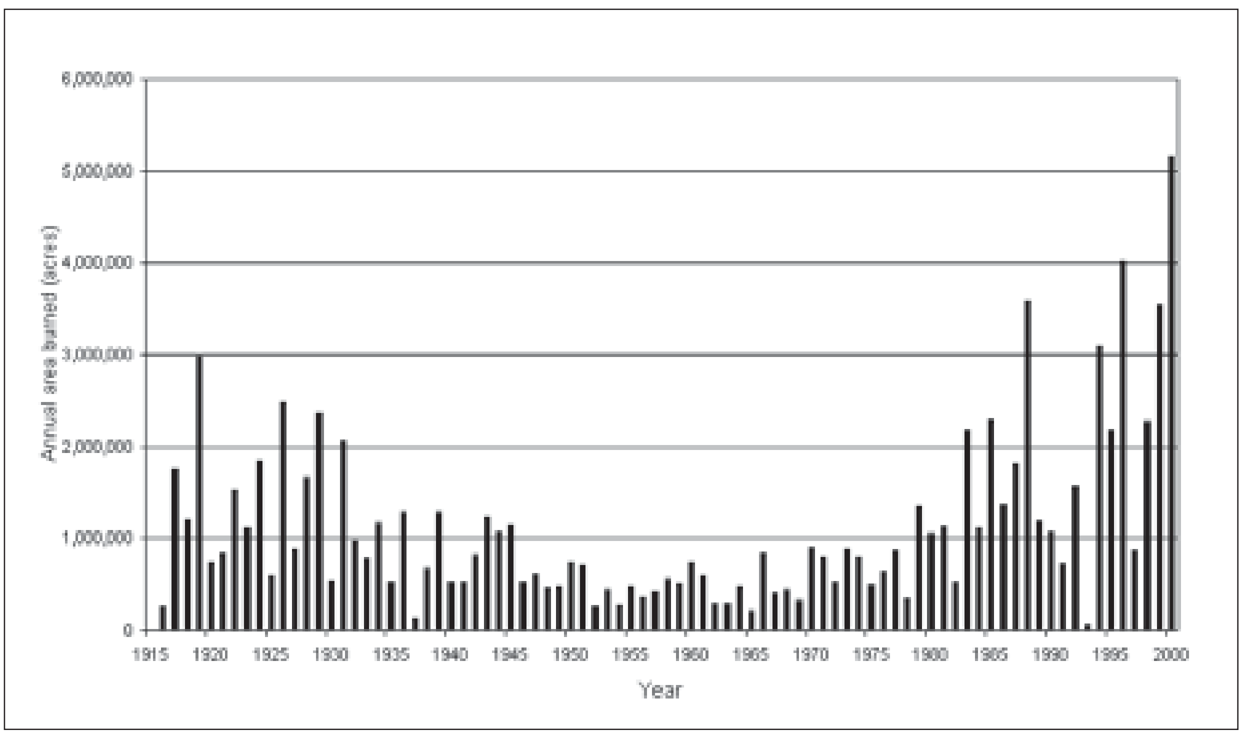


Figure 2.4. The average annual burned area for the western States, shown here for the period 1916-2000, has generally been increasing since the mid-1960s

Wildland and Prescribed Fire Terminology Update

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

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

Taking Action: The Federal Wildland and Prescribed Fire Policy

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

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

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

USDI and USDA Forest Service 1995—cover memorandum

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

Literature Citations

Agee, J.K. 1993. Fire Ecology of Pacific Northwest Forests. Island Press, Washington, DC.

Bond, W.J. and B.W. van Wilgen. 1996. Fire and Plants. Chapman Hall, London.

Brown, J.K. and J. Kapler Smith (eds.). 2000. Wildland Fire in Ecosystems: Effects of Fire on Flora. Gen. Tech. Rep. RMRS-GTR-42-vol.2. Ogden, UT.

Chavez Ramirez, F., H.E. Hunt, R.D. Slack and T.V. Stehn. 1996. Ecological correlates of Whooping Crane use of fire-treated upland habitats. Conservation Biology 10:217-223.

Cooper, C.F. 1961. The ecology of fire. Sci. Am. 204(4):150-160.

Copenheaver, C.A., A.S. White and W.A. Patterson. 2000. Vegetation development in a southern Maine pitch pine-scrub oak barren. Journal Torrey Botanical Soc.127:19-32.

Ferry, G.W. R.G. Clark, R.E. Montomery, R.W. Mutch, W.P. Leenhouts, and G. T. Zimmerman. 1995. Altered fire regimes within fire-adapted ecosystems. Pages 222-224. In: Our Living Resources. W.T. LaRoe, G. S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac eds. U.S. Department of the Interior, National Biological Service, Washington, D.C. 530p.

Gilliam, F.S. and W.J. Platt. 1999. Effects of long-term fire exclusion on tree species composition and stand structure in an old-growth *Pinus palustris* (Longleaf pine) forest. Plant Ecology 140:15-26.

Gray, G.L. 1992. Health emergency imperils western forests. Resource Hotline. 8(9). Published by American Forests.

Hardy, C. C., D. E. Ward, and W. Einfeld. 1992. PM2.5 emissions from a major wildfire using a GIS: rectification of airborne measurements. In: Proceedings of the 29th Annual Meeting of the Pacific Northwest International Section, Air and Waste Management Association, November 11-13, 1992, Bellevue, WA. Pittsburgh, PA: Air and Waste Management Association.

Heinselman, M. L. 1978. Fire in wilderness ecosystems. In: Wilderness Management. J. C. Hendee, G. H. Stankey, and R. C. Lucas, eds. USDA Forest Service, Misc. Pub. 1365

Hermann, S.M., T. Van Hook, R.W. Flowers, L.A. Brennan, J.S. Glitzenstein, D.R. Streng, J.L. Walker and R.L. Myers. 1998. Fire and biodiversity: studies of vegetation and arthropods. Trans. North American Wildlife and Natural Resources Conf. 63:384-401

Johnson, E.A. 1992. Fire and Vegetation Dynamics: Studies from the North American Boreal Forest. Cambridge University Press, Cambridge.

Keeley, J.E., and C.J. Fotheringham. 1997. Trace gas emissions and smoke induced seed germination. Science 276:1248-1250.

Kilgore, B. M., and M. L. Heinselman. 1990. Fire in wilderness ecosystems. In: Wilderness Management, 2nd ed. J. C. Hendee, G. H. Stankey, and R. C. Lucas, eds. North American Press, Golden, CO. Pp. 297-335.

Kwilosz, J.R. and R.L. Knutson. 1999. Prescribed fire management of Karner blue butterfly habitat at Indiana Dunes National Lakeshore. Natural Areas Journal 19:98-108

Leenhouts, Bill. 1998. Assessment of biomass burning in the conterminous United States. Conservation Ecology [online] 2(1): 1. Available from the Internet. URL:

Mutch, R. W. 1994. Fighting fire with prescribed fire—a return to ecosystem health. J. For. 92(11):31-33.

Mutch, R. W. 1997. Need for more prescribed fire: but a double standard slows progress. In Proceedings of the Environmental Regulation and Prescribed Fire Conference, Tampa, Florida. March 1995. Pp. 8-14.

Myers, R.L. 1990. Scrub and high pine. pages 150-193 *in* (R.L. Myers and J.J. Ewel, eds.) Ecosystems of Florida. University of Central Florida Press, Orlando.

National Wildfire Coordinating Group (NWCG). 1998. Managing Wildland Fire: Balancing America's Natural Heritage and the Public Interest. National Wildfire Coordinating Group; Fire Use Working Team [online]. Available from the Internet. URL: http://www.fs.fed.us/fire/fire_new/fireuse/wildland_fire_use/role/role_pg8.html

Smith, J. Kapler (ed.). 2000. Wildland fire in ecosystems: effects of fire on fauna. Gen. Tech. Rep. RMRS-GTR-42-vol. 1. Ogden, UT.

Swain, A. 1973. A history of fire and vegetation in northeastern Minnesota as recorded in lake sediment. Quat. Res. 3: 383-396.

Swetnam, T. W. 1993. Fire history and climate change in giant sequoia groves. Science. 262:885-889.

USDI and USDA Forest Service. 1995. Federal wildland fire management policy and program review. Final report. National Interagency Fire Center, Boise, ID. 45 pp.

USDI and USDA Forest Service. 1998. Wildland and prescribed fire management policy—implementation procedures reference guide. National Interagency Fire Center, Boise, ID. 81 pp. and appendices.

U.S. Environmental Protection Agency. 1998. Interim air quality policy on wildland and prescribed fires. Final report. U.S. Environmental Protection Agency.

Wade, D.D., J.J. Ewel, and R. Hofsetter. 1980. Fire in South Florida Ecosystems. USDA Forest Service General Technical Report SE-17.

Walker, J. 1993. Rare vascular plant taxa associated with the longleaf pine ecosystems: patterns in taxonomy and ecology. pages 105-125 in (S.M. Hermann, ed.), The Longleaf Pine Ecosystem: ecology, restoration, and management. Proceedings of the Tall Timbers Fire Ecology Conference, No. 18.

Watts, W.A., B.C.S. Hansen and E.C. Grimm. 1992. Camel Lake – A 4000-year record of vegetational and forest history from northwest Florida. Ecology 73:1056-1066.

Weaver, H. 1943. Fire as an ecological and silvicultural factor in the ponderosa pine region of the Pacific Slope. J. For. 41:7-14.

Whelan, R.J. 1995. The Ecology of Fire. Cambridge University Press, Cambridge.

The Smoke Management Imperative

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

Introduction

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

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

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

Purpose of a Smoke Management Program

The purpose of a smoke management program is to:

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

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

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

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

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

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

The Need for Smoke Management Programs

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

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

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

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

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

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

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

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

---

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

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

[4] [40 CFR Part 51]

Past Success and Commitment to Future Efforts

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

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

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

Chapter 3

SMOKE IMPACTS

Public Health and Exposure to Smoke

John E. Core

Janice L. Peterson

Introduction

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

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

Human Health Effects of Particulate Matter

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

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

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

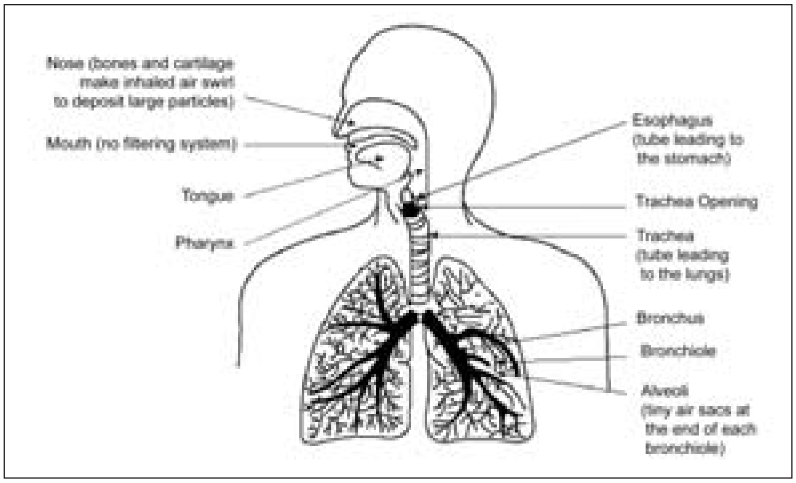


Figure 3.1.1: Particle deposition in the respiratory system.
From: Canadian Center for Occupational Health & Safety, available at http://www.ccohs.ca/oshanswers/ chemicals/how_do.html

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

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

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

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

Impacts of Wildland Fire Smoke on Public Health

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

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

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

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

Other Pollutants of Concern in Smoke

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

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

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

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

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

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

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

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

Conclusions

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

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

Wildfire Smoke and Your Health

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

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

What can I do to protect myself?

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

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

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

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

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

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

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

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

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

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

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

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

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

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

This document was prepared by the Air Program, U.S. Forest Service – Northern Region, with assistance from the Office of Air Quality Planning & Standards in the US Environmental Protection Agency. For more information, call 406-329-3493. August 2000.

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

Literature Citations

Brauer, Michael. 1999. Health impacts of biomass air pollution. In: Health guidelines for vegetation fire events: background papers. Edited by Kee-Tai Goh, Dietrich Schwela, Johann G. Goldammer, and Orman Simpson. World Health Organization. Available at http://www.who.int/peh/air/vegetationfirbackgr.htm. 69p.

Dockery DW, Pope CA III, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG Jr, and Speizer FE. 1993. An association between air pollution and mortality in six U.S. cities. New England Journal of Medicine. 329:1753-1759.

Environmental Protection Agency-Region 8. 1997. Public health effects of ozone and fine particle pollution. Environmental Fact Sheet. Available at http://www.epa.gov/region08/news/news9697/ofpo.html

Environmental Protection Agency. 1996. Air quality criteria for particulate matter - Volume 1. US Environmental Protection Agency, Research Triangle Park, NC. EPA/600/P-95/001aF.

Environmental Protection Agency. 1999. Guideline for reporting of daily air quality – air quality index (AQI). EPA-454/R-99-010. U.S. EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. 25p.

Federal Register. 1997. Memorandum from the President re: Implementation of Revised Air Quality Standards for Ozone and Particulate Matter. Federal Register Vol. 62, No. 138. July 18, 1997.

Morgan, Michael S. 1989. Health risks from slash fire smoke. In: The Burning Decision – Regional Perspectives on Slash. University of Washington College of Forest Resources. Seattle, WA. pp. 226-236.

Sharkey, Brian, ed. 1997. Health hazards of smoke: recommendations of the April 1997 Consensus Conference. Tech. Rep. 9751-2836-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 84 p.

Therriault, Shannon. 2001. Wildfire smoke: a guide for public health officials. Missoula City-County Health Department. Missoula, MT. 13p. Available at: http://depts.washington.edu/wildfire/resources/pubhealthguide.pdf

Visibility

John E. Core

Introduction

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

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

Measures of Visibility Impairment

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

Properties of the Atmosphere & Wildland Fire Smoke

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

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

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

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

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

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

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

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

Natural Visibility Conditions

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

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

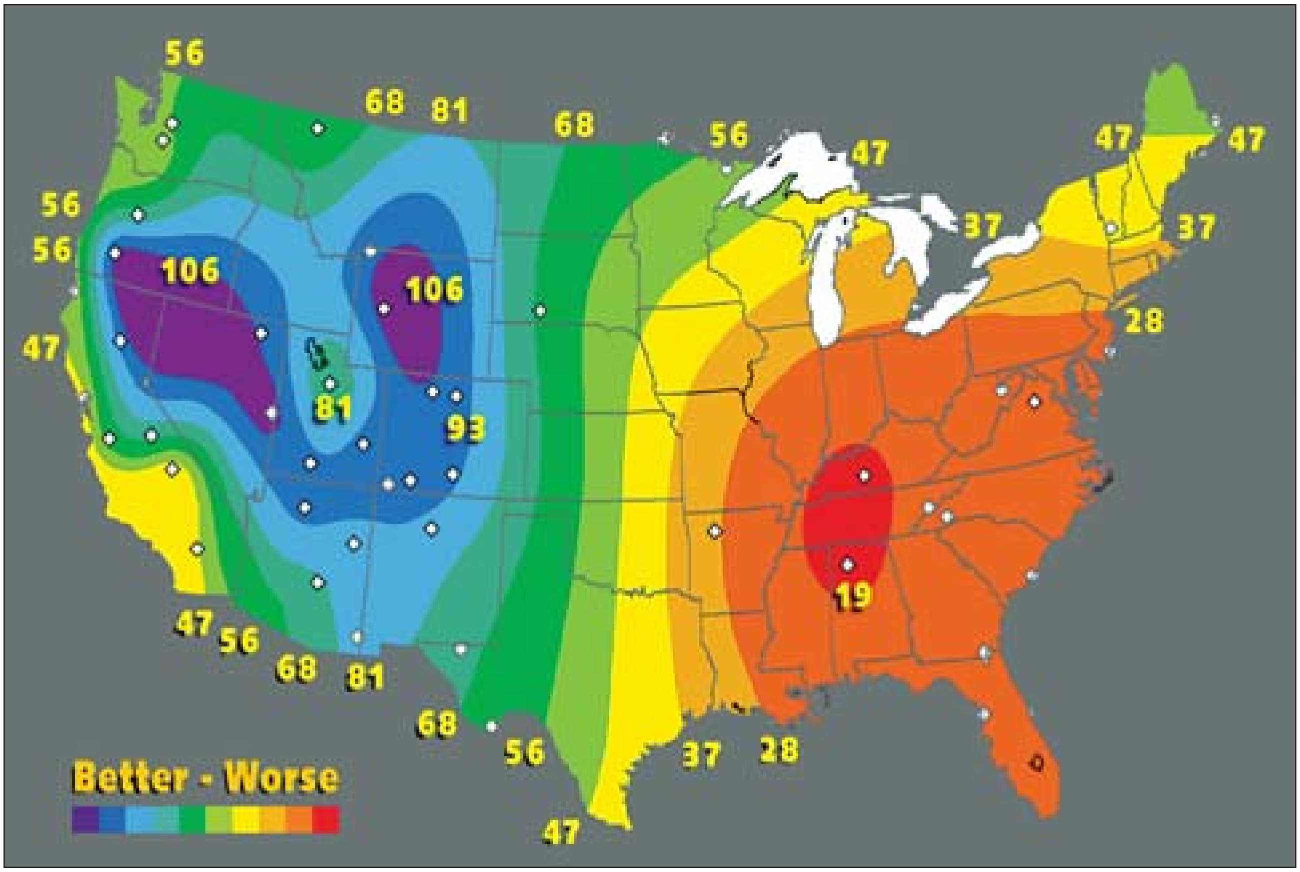


Figure 3.2.2. *Average annual visual range, in miles, for the years 1996-1998 measured at IMPROVE network monitors.*

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

Current Visibility Conditions

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

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

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

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

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

Literature Citations

IMPROVE. 1994. Visibility protection. Interagency Monitoring of Protected Visual Environments Brochure. Ft. Collins, Colorado. August 1994. Available at: www2.nature.nps.gov/ard/impr/index.htm

National Park Service. 1997. Visibility protection. National Park Service Air Resources Division Web Page. Available at www2.nature.nps.gov/ard/vis/visprot.html

Malm, William C. 1999. Introduction to visibility. Cooperative Institute for Research in the Atmosphere. NPS Visibility Program, Colorado State University, Fort Collins, CO: 79 p.

Problem and Nuisance Smoke

Gary L. Achtemeier

Bill Jackson

James D. Brenner

Introduction

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

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

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

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

Nuisance Smoke and Visibility Reduction

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

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

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

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

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

Smoke as a Southern Problem

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

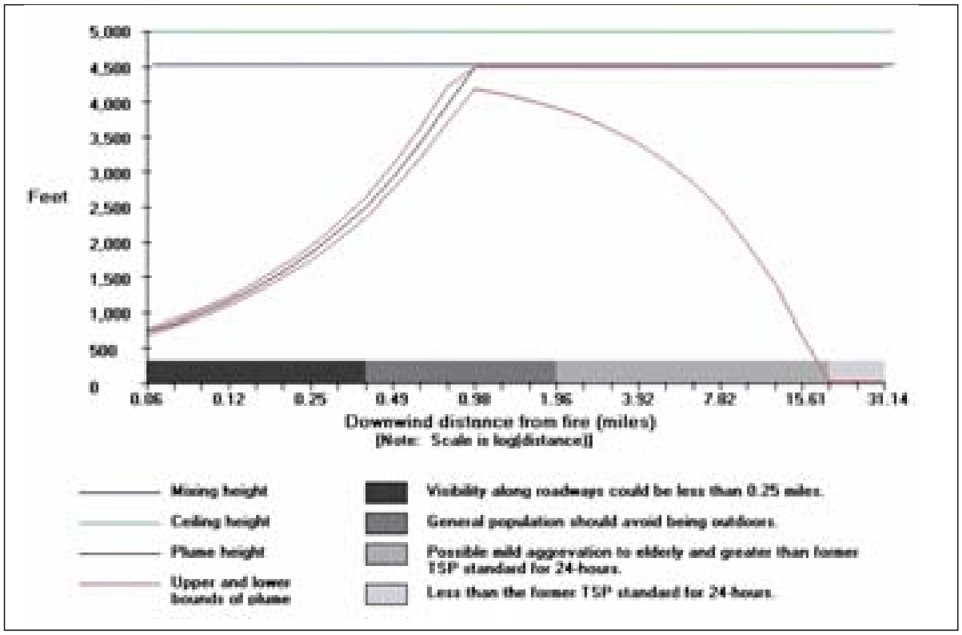


Figure 3.3.1. Graphic from the dispersion model VSmoke-GIS, showing the rise and descent of a smoke plume during a daytime prescribed fire, assuming 25% of the smoke disperses at ground level.

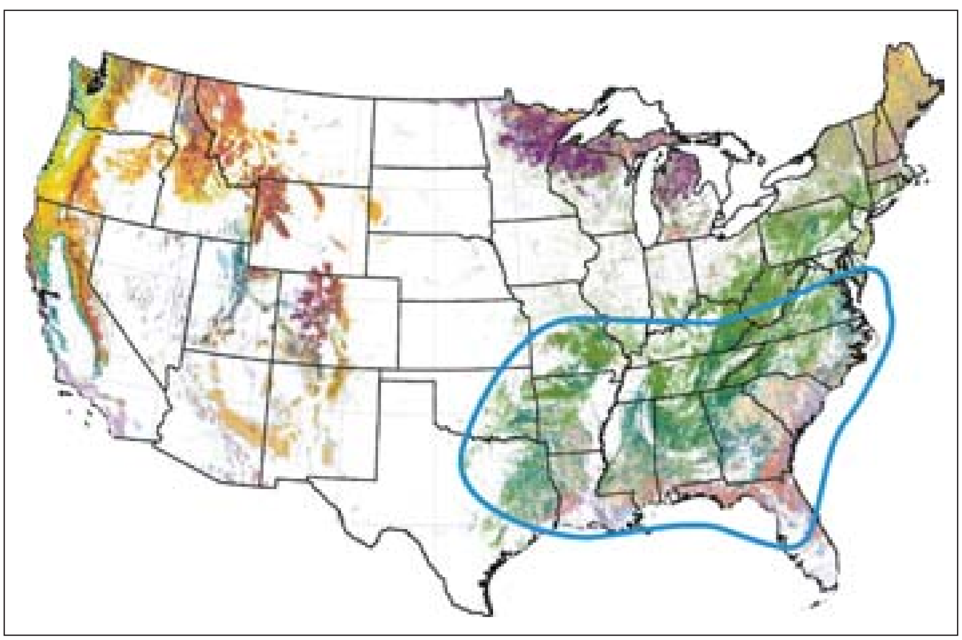


Figure 3.3.2. National Atlas of Forest Cover Types. Southern forests (outlined in blue extend from Virginia to Texas and from the Ohio River southward and account for approximately 40% of U.S. forest land.

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

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

Smoke and Southern Climate

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

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

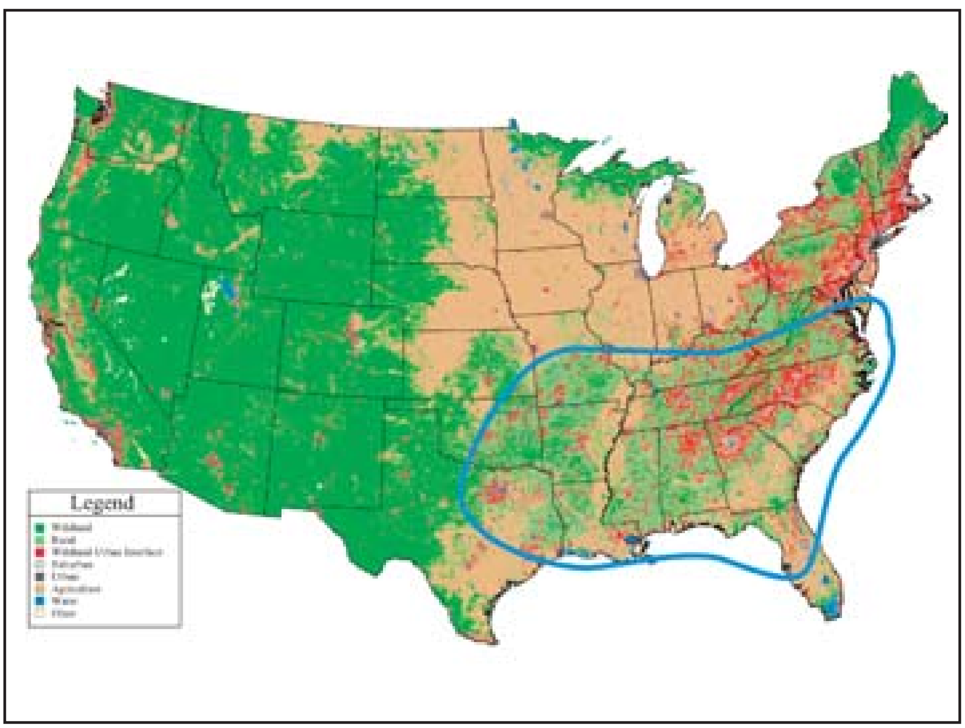


Figure 3.3.3. Population density classes showing wildland/urban interface in red. Southern forests outlined in blue. [http://www.fs.fed.us/fire/fuelman]

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

Smoke and Southern Meteorology

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

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

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

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

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

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

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

Smoke and Southern Highways

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

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

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

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

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

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

Problem Smoke: What is being done to Minimize the Problem

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

- Several states have devised smoke management guidelines to regulate the amount of smoke put into the atmosphere from prescribed burning. The South Carolina Forestry Commission (1998) has established guidelines to define smoke sensitive areas, amounts of vegetative debris that may be burned, and atmospheric conditions suitable for burning this debris.
- The Forestry Weather Interpretation System (FWIS) was developed by the U.S. Forest Service in the late 1970's and early 1980's in cooperation with the southern forestry community (Paul 1981; Paul and Clayton 1978). The system has been enhanced and automated by the Georgia Forestry Commission (Paul et al. 2000) to serve forestry sources in Georgia and clients in other southern states. The GFC provides weather information and forecasts specified for forest districts, and indices used for interpretations for smoke management, prescribed fire, fire danger, and fire behavior. Indices include the Keetch-Byram Drought Index, National Fire Danger Rating System, Ignition component, Burning Index, and Manning Class Day.

- High resolution weather prediction models promise to provide increased accuracy in predictions of wind speeds and directions and mixing heights at time and spatial scales useful for land managers. The Florida Division of Forestry (FDOF) is a leader in the use of high resolution modeling for forestry applications in the South (Brackett et al. 1997). Accurate predictions of sea/land breezes and associated changes in temperature, wind direction, atmospheric stability and mixing height are critical to the success of the FDOF system as much of Florida is located within 20 miles of a coastline. High resolution modeling consortia are also being established by the U.S. Forest Service to serve clients with interests as diverse as fire weather, air quality, oceanography, ecology, and meteorology.

- Several smoke models are in operation or are being developed to predict smoke movement over Southern landscapes. VSMOKE (Lavdas 1996), a Gaussian plume model that assumes level terrain and unchanging winds, predicts smoke movement and concentration during the day. VSMOKE is now part of the FDOF fire and smoke prediction system. It is a screening model that aids land managers in assessing where smoke might impact sensitive targets as part of planning for prescribed burns. PB-Piedmont (Achtemeier 2001) is a wind and smoke model designed to simulate smoke movement near the ground under entrapment conditions at night. The smoke plume is simulated as an ensemble of particles that are transported by local winds over complex terrain characteristic of the shallow (30-50 m) interlocking ridge/valley systems typical of the Piedmont of the South. PB-Piedmont does not predict smoke concentrations as emissions from smoldering combustion are usually not known. Two sister models are planned, one that will simulate near ground smoke movement near coastal areas influenced by sea/land circulations and the other for the Appalachian mountains.

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

Literature Citations

Achtemeier, G.L. 2001. Simulating nocturnal smoke movement. Fire Management Today, 61: 28-33

Achtemeier, G. L. 1993. Measurements of drainage winds along a small ridge. In: Proceedings of the 86th Annual Meeting and Exhibition, Air & Waste Management Association, 93-FA-155.06, 15 pp.

Brackett, D.P., L. G. Arvanitus, J. Brenner, and M. Long, 1997. A high-tech approach to open-burning authorization and wildfire response. J. Forestry, 95: 10-15.

Eshee, W.D. 1995. Legal implications of using prescribed fire. In: Proceedings: Environmental regulation & prescribed fire conference. D.C. Bryan, ed. Division of Forestry, Florida Department of Agriculture and Consumer Services, Tallahassee, Florida. pp. 126-130.

Lavdas, L. G. 1996. Program VSMOKE–users manual. USDA Forest Service General Technical Report SRS-6. 147 pp.

Lavdas, L., and G. L. Achtemeier. 1995. A fog and smoke risk index for estimating roadway visibility hazard. National Weather Digest, 20: 26-33.

Mobley, H. E. 1989. Summary of smoke-related accidents in the South from prescribed fire (1979-1988). American Pulpwood Association Technical Release 90-R-11.

New Mexico Environmental Improvement Board Rules. 1995. Open Burning 20-NMAC2.60. Santa Fe, New Mexico.

Paul, J. T., 1981: A real-time weather system for forestry (FWIS). Bulletin of the American Meteorological Society, 62: 1466-1472.

Paul, J. T., and J. Clayton, 1978. User manual: Forestry Weather Interpretation System (FWIS). Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station and Atlanta, GA: Southeastern Area State and Private Forestry, in cooperation with the U.S. National Weather Service, NOAA, Silver Spring, MD, 83pp.

Paul, J. T., D. Chan, and A. Dozier, 2000. Fire Weather and Smoke Management System. Georgia Forestry Commission, 74 pp.

Sandberg, D.V., and F. N. Dost. 1990. Effects of prescribed fire on air quality and human health. In: Natural and Prescribed Fire in Pacific Northwest Forests. J.D. Walstad; S.R. Radosevich; D.V. Sandberg, eds. Oregon State University Press, Corvallis, OR. pp. 91-298.

Shelby, B., and R. W. Speaker. 1990. Public attitudes and perceptions about prescribed burning. In: J.D. Walstad; S.R. Radosevich; D.V. Sandberg, eds. Natural and Prescribed Fire in Pacific Northwest Forests. Oregon State University Press. Corvallis, OR. pp. 253-260.

South Carolina Forestry Commission, 1998. Smoke Management Guidelines for Vegetative Debris Burning Operations in the State of South Carolina. SCFC 4th Printing, 21 p.

State of Oregon Department of Forestry. 1992. Smoke Management Program Directives, Appendix 2. Salem, Oregon.

State of Washington Department of Natural Resources. 1993. Smoke Management Program Appendix 5. Olympia, Washington.

Supreme Court of Iowa, No. 192/96-2276. Bormann, et al vs. Board of Supervisors in and for Kossuth County Iowa. September 23, 1998. {http://www.webcom.com/bi /iowa.htm}

US Environmental Protection Agency. 1990. Air Quality Criteria for Particulate Matter Volume II of III. Office of Research and Development. EPA/600/P-95/00ibF. pp. 8-82 – 8-89.

Smoke Exposure Among Fireline Personnel

Roger D. Ottmar

Timothy R. Reinhardt

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

Health Hazards in Smoke

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

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

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

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

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

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

Evaluation Criteria

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

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

Table 3.4.1. Occupational exposure limits[a]

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

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

Smoke Exposure at Prescribed Burns and Wildfires

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

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

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

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

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

Monitoring Smoke Exposure of Fireline workers

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

Respirator Protection

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

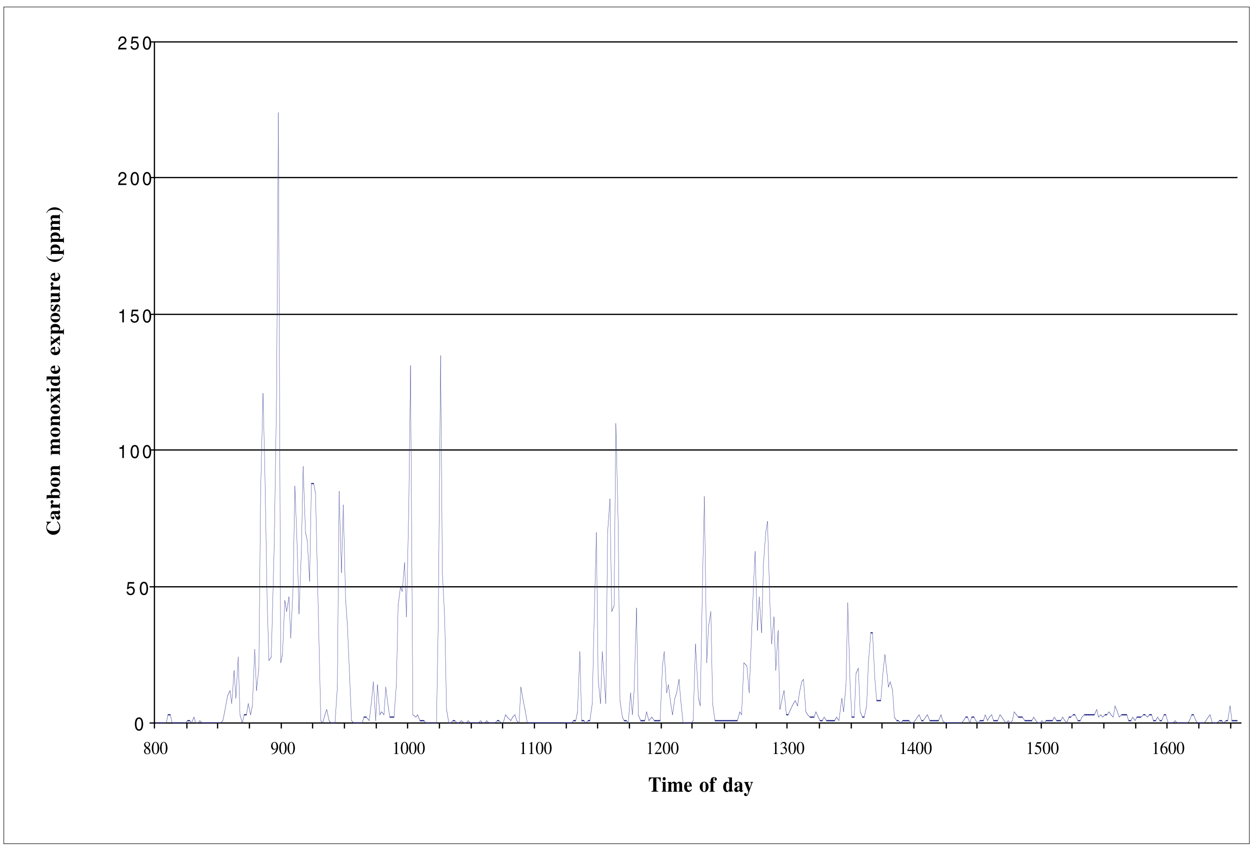


Figure 3.4.2. Carbon monoxide exposure data from a electronic CO data recorder for a fireline worker during a work-shift on a prescribed fire (Reinhardt and others 2000)

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

Management Implications

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

Literature Citations

American Conference of Governmental Industrial Hygienists. 2000. 2000 TLVs® and BEIs®: Threshold Limit Values for chemical substances and physical agents and biological exposure indices. Cincinnati, OH 192 p.

Betchley, C.; Koenig, J.Q.; van Belle G.; Checkoway, H. and Reinhardt, T. 1995. Pulmonary function and respiratory symptoms in forest firefighters, Unpublished report, University of Washington, Departments of Environmental Health and Epidemiology, Seattle, WA

Booze, Tom F.; Reinhardt, Timothy E. 1996. Assessment of the health risks of chronic smoke exposure for wildland firefighters. Unpublished report, Pacific Northwest Research Station, Seattle forestry Science Laboratory, 4043 Roosevelt Way N.E., Seattle, WA. 29 p.

Coburn, R.F.; Forster, R.E.; Kane, P.B. 1965. Considerations of the physiological variables that determine the blood carboxyhemoglobin concentration in man. Journal of Clinical Investigation 44: 1899-1910.

Dost, F.N. 1991. Acute toxicology of components of vegetation smoke. In: Reviews of Environmental Contamination and Toxicology, Vol 119, Springer-Verlag New York, Inc., New York, NY, 1991 pp 2-46.

Kane, L.E.; Alarie, Y. 1977. Sensory irritation to formaldehyde and acrolein during single and repeated exposures in mice. American Industrial Hygiene Association Journal 38(10): 509-522.

Letts, D.; Fidler, A.T.; Deitchman, S.; Reh, C.M. 1991. Health hazard evaluation report 91-152-2140. U.S. Department of the Interior, National Park Service, Southern California, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Cincinnati, OH.

Reh, C.M.; Letts, D.; Deitchman, S.D. 1994. Health hazard evaluation report 90-0365-2415. U.S. Department of the Interior, National Park Service, Yosemite National Park, California, U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, Cincinnati, OH.

Reinhardt, Timothy E.; Ottmar, Roger D. 1997. Smoke exposure among wildland firefighters: a review and discussion of current literature. Gen. Tech. Rep. GTR-373. Portland, OR: U.S. Department of Agriculture, Forest service, Pacific Northwest research Station. 61 p.

Reinhardt, Timothy E.; Ottmar, Roger D. 2000. Smoke exposure at western wildfires. Res. Pap. PNW-RP-525. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p.

Reinhardt, Timothy E.; Ottmar, Roger D.; Hanneman, Andrew J.S. 2000. Smoke exposure among firefighters at prescribed burns in the Pacific Northwest. Res. Pap. PNW-RP-526. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 45 p.

Reinhardt, Tim E.; Ottmar, Roger D.; Hallett, Michael R. 1999. Guide to monitoring smoke exposure of wildland firefighters. Gen. Tech. Rep. PNW-GTR-448. Portland, OR: U.S. Department of Agriculture, Forest service, Pacific Northwest Research Station. 17 p.

Sandberg, David V.; Dost, Frank N. 1990. Effects of prescribed fire on air quality and human health. In: Walstad, John D.; Radosevich, Steven R.; Sandberg, David V., eds. Natural and prescribed fire in the Pacific Northwest forests. Corvallis, OR: Oregon State University Press: 191-298.

Sharkey, Brian, ed. 1997. Health hazards of smoke: recommendations of the April 1997 Consensus Conference. Tech. Rep. 9751-2836-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 84 p.

Sharkey, Brian, ed. 1998. Health hazards of smoke. Closed caption video. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 19 minutes.

Thompson, S.; Sharkey, B. 1966. Physiological cost and air flow resistance of respiratory protective devices. Ergonomics 9:495.

U.S. Department of Labor, Occupational Safety and Health Admnistration. 1987. Occupational exposure to formaldehyde, final rule. Federal Register 52(233): 46312, Washington D.C. 1987.

U.S. Department of Labor, Occupational Safety and Health Administration. 1994. Code of Federal Regulations, Title 29, Part 1910.1048(d)(2)(i), Washington, DC, 1994.

Chapter 4

REGULATIONS

Regulations For Smoke Management

Janice L. Peterson

Some of the components of smoke from prescribed fire are regulated air pollutants. And, as with any other rule or regulation, fire managers must understand and follow federal, state, and local regulations designed to protect the public against possible negative effects of air pollution.

Air pollution is defined as the presence in the atmosphere of a substance or substances added directly or indirectly by a human act, in such amounts as to adversely affect humans, animals, vegetation, or materials (Williamson 1973). Air pollutants are classified into two major categories: **primary** and **secondary**. **Primary pollutants** are those directly emitted into the air. Under certain conditions, primary pollutants can undergo chemical reactions within the atmosphere and produce new substances known as **secondary pollutants**.

Emissions from prescribed fire are managed and regulated through an often-complex web of interrelated laws and regulations. The overarching law that is the foundation of air quality regulation across the nation is the Federal Clean Air Act (Public Law 95-95).

Federal Clean Air Act

In 1955, Congress passed the first Federal Clean Air Act with later amendments in 1967, 1970, 1977, and 1990. The Clean Air Act is a legal mandate designed to protect public health and welfare from air pollution. States develop specific programs for implementing the goals of the Clean Air Act through their State Implementation Plans (SIP's). States may develop programs that are more restrictive than the Clean Air Act requires but never less. Burners must know the specifics of state air programs and how fire emissions are regulated to responsibly conduct a prescribed fire program.

Roles and Responsibilities

Although the Clean Air Act is a federal law and therefore applies to the entire country, the states do much of the work of implementation. The Act recognizes that states should have the lead in carrying out provisions of the Clean Air Act, since appropriate and effective design of pollution control programs requires an understanding of local industries, geography, transportation, meteorology, urban and industrial development patterns, and priorities.

The Clean Air Act gives the Environmental Protection Agency (EPA) the task of setting limits on how much of various pollutants can be in the air where the public has access[1] (ambient air). These air pollution limits are the National Ambient Air Quality Standards or NAAQS and

[1] Note that the Occupational Safety and Health Administration (OSHA), rather than EPA, sets air quality standards for worker protection.

are intended to be established regardless of possible costs associated with achieving them, though EPA is allowed to consider the costs of controlling air pollution during the implementation phase of the NAAQS in question. In addition, EPA develops policy and technical guidance describing how various Clean Air Act programs should function and what they should accomplish. States develop State Implementation Plans (SIPs) that define and describe customized programs that the state will implement to meet requirements of the Clean Air Act. Tribal lands are legally equivalent to state lands and tribes prepare Tribal Implementation Plans (TIPs) to describe how they will implement the Clean Air Act. The individual states and tribes can require more stringent pollution standards, but cannot weaken pollution goals set by EPA. The Environmental Protection Agency must approve each SIP/TIP, and if a proposed or active SIP/TIP is deemed inadequate or unacceptable, EPA can take over enforcing all or parts of the Clean Air Act requirements for that state or tribe through implementation of a Federal Implementation Plan or FIP (figure 4.1.1).

National Ambient Air Quality Standards

The primary purpose of the Clean Air Act is to protect humans against negative health or welfare effects from air pollution. National Ambient Air Quality Standards (NAAQS) are defined in the Clean Air Act as amounts of pollutant above which detrimental effects to public health or welfare may result. NAAQS are set at a conservative level with the intent of protecting even the most sensitive members of the public including children, asthmatics, and persons with cardiovascular disease. NAAQS

FEDERAL CLEAN AIR ACT

EPA Responsibilities
1. Establish NAAQS.
2. Develop policy and technical guidance for states/tribes.
3. Approve SIPs/TIPs and control measures.
4. Backup to state enforcement.
5. Administer air grant money.

STATE AND TRIBAL IMPLEMENTATION PLANS

State and Tribe Responsibilities
1. Develop SIPs or TIPs that meet Clean Air Act requirements and submit to EPA for approval.
2. Implement SIP/TIP programs.
3. Develop and maintain emission inventories.
4. Conduct air quality monitoring.
5. Establish and operate a permitting program for new and existing air pollution sources.

Figure 4.1.1. Role of EPA and the states and tribes in Clean Air Act implementation.

have been established for the following criteria pollutants: particulate matter[2] (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone, carbon monoxide and lead (table 4.1.1). Primary NAAQS are set at levels to protect public health; secondary NAAQS are to protect public welfare. The standards are established for different averaging times, for example, annual, 24-hour, and 3-hour.

The major pollutant of concern in smoke from wildland fire is fine particulate matter, both PM_{10} and $PM_{2.5}$. Studies indicate that 90 percent of smoke particles emitted during wildland burning are PM_{10} and about 90 percent of PM_{10} is $PM_{2.5}$ (Ward and Hardy 1991). 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

Table 4.1.1. National Ambient Air Quality Standards.

Pollutant / Time-weighted period	Standard[a] Primary	Standard[a] Secondary
PM_{10}		
Annual Arithmetic Mean	50 $\mu g/m^3$	50 $\mu g/m^3$
24-hour Average	150 $\mu g/m^3$	150 $\mu g/m^3$
$PM_{2.5}$		
Annual Arithmetic Mean	15 $\mu g/m^3$	15 $\mu g/m^3$
24-hour Average	65 $\mu g/m^3$	65 $\mu g/m^3$
Sulfur Dioxide (SO_2)		
Annual Average	0.03 ppm	– –
24-hour Average	0.14 ppm	– –
3-hour Average	– –	0.50 ppm
1-hour Average	– –	– –
Carbon Monoxide (CO)		
8-hour Average	9 ppm	– –
1-hour Average	35 ppm	– –
Ozone (O_3)		
1-hour Average	0.12 ppm	0.12 ppm
8-hour Average	0.08 ppm	0.08 ppm
Nitrogen Dioxide (NO_2)		
Annual Average	0.053 ppm	0.053 ppm
Lead (Pb)		
Quarterly Average	1.5 $\mu g/m^3$	1.5 $\mu g/m^3$

[a] $\mu g/m^3$ = micrograms per cubic meter; ppm = parts per million

[2] Particulate matter NAAQS are established for two aerodynamic diameter classes: PM_{10} is particulate matter 10 micrometers or less in diameter, and $PM_{2.5}$ is particulate matter that is 2.5 micrometers or less in diameter.

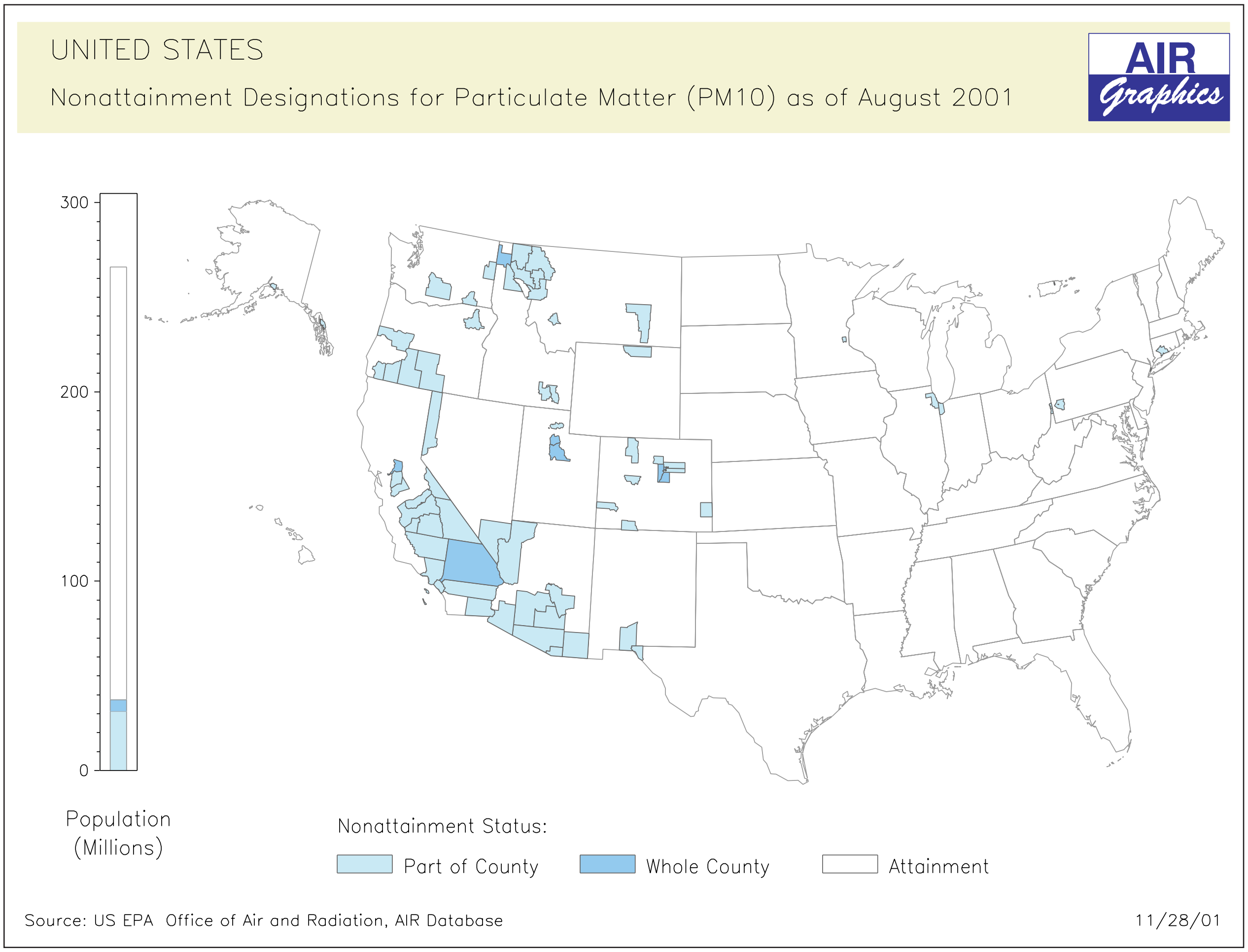


Figure 4.1.2. PM_{10} nonattainment areas as of August 2001. See the EPA AIR*Data* web page for current nonattainment status for PM_{10} and al other criteria pollutants (http://www.epa.gov/air/data/mapview.html).

mortality, exacerbation of chronic disease, and increased hospital admissions (Dockery and others 1993, EPA 1996).

An area that is found to be in violation of a primary NAAQS is labeled a non-attainment area (figure 4.1.2). An area once in non-attainment but recently meeting NAAQS, and with appropriate planning documents approved by EPA, is a maintenance area. All other areas are attainment or unclassified (due to lack of monitoring). State air quality agencies can provide up-to-date locations of local non-attainment areas[3]. States are required through their SIP's to define programs for implementation, maintenance, and enforcement of the NAAQS within their boundaries. A non-attainment designation is a black mark on the states air agency's ability to protect citizens from the negative effects of air pollution so states generally develop aggressive programs for bringing non-attainment areas into compliance with clean air goals. Wildland fire in and near non-attainment areas will be scrutinized to a greater degree than in attain-

[3] $PM_{2.5}$ is a newly regulated pollutant so attainment/non-attainment status has not yet been determined. Monitoring must take place for at least 3 years before a designation can be made.

ment areas (and may be subject to General Conformity rules, see section 4.3: Federal Land Management-Special Requirements). Extra pre-planning, documentation, and careful scheduling of wildland fires will likely be required to minimize smoke effects in the non-attainment area to the greatest extent possible. In some cases, the use of fire may not be possible if significant impacts to a non-attainment area are likely.

Natural Events Policy

PM_{10} NAAQS exceedences caused by natural events are not counted toward non-attainment designation if a state can document that the exceedance was truly 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[4]. Natural events are defined by this policy as wildfire, volcanic and seismic events, and high wind events. Prescribed fires used to mimic the natural role of fire in the ecosystem are not considered natural events under this policy. In response to this potential conflict of terms, the Interim Air Quality Policy on Wildland and Prescribed Fires (EPA 1998) states that EPA will exercise its discretion not to redisignate an area as non-attainment if the evidence is convincing that fires managed for resource benefits caused or significantly contributed to violations of the daily or annual $PM_{2.5}$ or PM_{10} standards and the state has a formal smoke management program (see Section 4.2: State Smoke Management Programs for more information).

A NEAP is developed by the state air pollution control agency in conjunction with the stakeholders affected by the plan. States should include input from Federal, state, and private land managers in areas vulnerable to fire when developing a wildland fire NEAP. Also, agencies responsible for suppressing fires, local health departments, and citizens in the affected area should be involved in developing the plan. The NEAP should include documented agreements among stakeholders as to planned actions and the parties responsible for carrying out those actions.

A wildfire NEAP should include commitments by the state and stakeholders to:

1. Establish public notification and education programs.
2. Minimize public exposure to high concentrations of PM_{10} due to future natural events such as by:
   - 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,
   - suggesting precautions to take if exposure cannot be avoided.
3. Abate or minimize controllable sources of PM_{10} including the following:
   - prohibition of other burning during pollution episodes caused by wildfire,
   - proactive efforts to minimize fuel loadings in areas vulnerable to fire,
   - planning for prevention of NAAQS exceedances in fire management plans.

[4] Nichols, Mary D. 1996. Memorandum dated May 30 to EPA Regional Air Directors. Subject: Areas Affected by PM_{10} Natural Events. Available from the EPA Technology Transfer Network, Office of Air and Radiation Policy and Guidance at http://www.epa.gov/ttn/oarpg.

4. Identify, study, and implement practical mitigating measures as necessary.
5. Periodic reevaluation of the NEAP.

Preparation of a NEAP provides the opportunity for land managers to formally document, in cooperation with state air agencies, that it is appropriate to consider prescribed fire a prevention, control, and mitigation measure for wildfire (see item 4 above). Prescribed fire can be used to minimize fuel loadings in areas vulnerable to fire so that future wildfires can be contained in a smaller area and will produce less emissions. This can lead to a greater understanding by state air agencies of the potential air quality benefits from some types of prescribed fire in certain ecosystems. A recent NEAP prepared for the Chelan county area of Washington State accomplished this goal[5]. The Chelan County NEAP recognizes planned efforts by the Wenatchee National Forest to reduce fuel loadings through thinning, pruning of lower branches, and careful use of prescribed fire as ways to minimize public exposure to particulate matter during wildfire season.

Hazardous Air Pollutants

Hazardous air pollutants or (HAPs) are identified in Title III of the Clean Air Act Amendments of 1990 (Public Law 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. Criteria pollutants (the six pollutants that are regulated through established National Ambient Air Quality Standards) are excluded from the list of HAPs.

De minimis Emission Levels

Air quality regulations allow omission of certain pollution sources in air quality impact analyses if they are considered very minor and are certain to have no detrimental effects. These sources are considered to emit pollutant amounts below de minimis levels. For example, burning a slash pile with less than 100 tons of material is not subject to permit or regulation in some areas. Emissions below de minimis levels are often excluded from air quality regulations so this is an important concept to define in reference to wildland fire. De minimis levels have been defined for many industrial sources but little guidance is available for many wildland activities including prescribed fire. Some states have locally defined de minimis levels for example in Utah, fires less than 20 acres per day in size and emitting less than 0.5 ton of total particulate per day are considered de minimis and can be ignited without permit if burners register the project and comply with clearing index procedures. Definition of de minimis levels is a topic that needs further discussion between wildland fire managers and regulatory agencies so guidance can be developed at the local and/or national level.

[5] Washington Department of Ecology. June 1997. Natural event action plan for wildfire particulate matter in Chelan County, Washington. 21p. Available from the Washington Department of Ecology, PO Box 47600, Olympia, WA 98504-7600.

Prevention of Significant Deterioration

Another provision of the Clean Air Act that sometimes comes up when discussing wildland burning activities is the Prevention of Significant Deterioration provisions or PSD. The goal of PSD is to prevent areas that are currently cleaner than is allowed by the NAAQS from being polluted up to the maximum ceiling established by the NAAQS. States and tribes 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.

Three air quality classes were established by the Clean Air Act, PSD provisions, including Class I, Class II, and Class III. Class I areas are subject to the tightest restrictions on how much additional pollution, or increment, can be added to the air. Class I areas include Forest Service wildernesses and national memorial parks over 5000 acres, National parks exceeding 6000 acres, and international parks, all of which must have been in existence as of August 7, 1977, plus later expansions to these areas (figure 4.1.3). 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, through a SIP or TIP, 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.

Historically, 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. 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.

Visibility

The 1977 amendments to the Clean Air Act established 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" (Public Law 95-95). States are required to develop implementation plans that make "reasonable progress" toward the national visibility goal.

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 we see. The fine particles most responsible for visibility impairment are sulfates, nitrates, organic compounds, elemental carbon (or soot), and soil dust. Sulfates, nitrates, organic carbon, and soil tend to scatter light, whereas elemental carbon tends to absorb light. Wildland fire

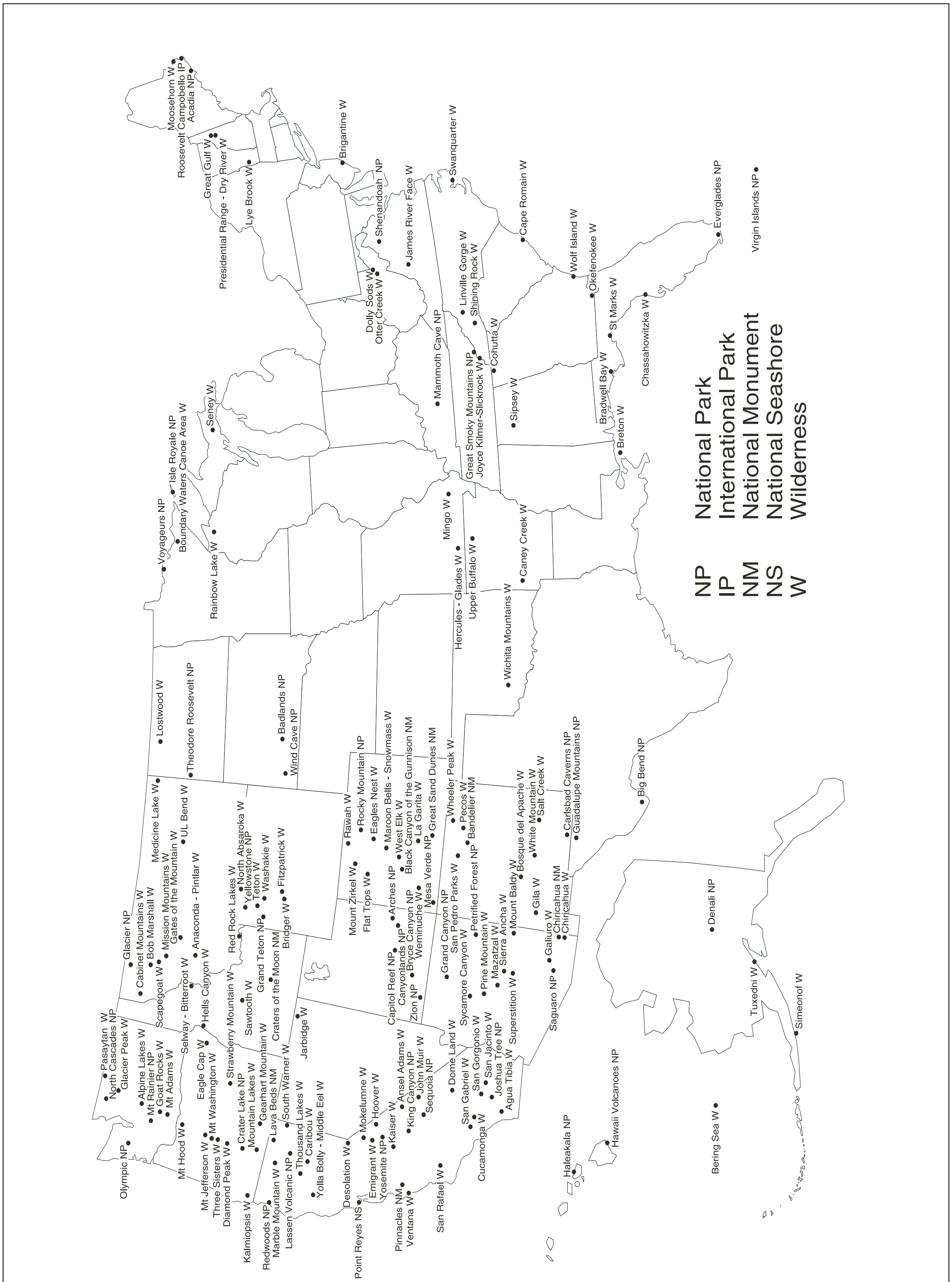


Figure 4.1.3. Mandatory Cass I areas.

smoke is primarily made up of elemental carbon, organic carbon, and particulate matter. Fine particles ($PM_{2.5}$) are more efficient per unit mass than coarse particles (PM_{10} and larger) at causing visibility impairment. Naturally occurring visual range in the East is estimated to be between 60 and 80 miles, while natural visual range in the West is between 110-115 miles (Trijonis and others 1991). Currently, visual range in the Eastern US is about 15 to 30 miles and about 60 to 90 miles in the Western US (40 CFR Part 51). The theoretical maximum visual range with nothing in the air except air molecules is about 240 miles.

Federal Land Managers (FLMs) have somewhat conflicting roles when it comes to protecting visibility in the Class I areas they manage. On the one hand, FLMs are given the responsibility by the Clean Air Act for reviewing PSD permits of major new and modified stationary pollution sources and commenting to the state on whether there is concern for visibility impacts (or other resource values) in Class I areas downwind of the proposed pollution source. In this case FLMs play a proactive role in air pollution prevention. On the other hand, however, FLMs also use wildland fire, which emits visibility-impairing pollutants. In this case the FLM is the polluter and is often in the difficult position of trying to explain why wildland burning smoke may be acceptable in wilderness whereas other types of air pollution are not. The answer to this dilemma is that wildernesses are managed to preserve and protect natural conditions and processes. So in this context, smoke and visibility impairment from wildland fire that closely mimics what would occur naturally is generally viewed as acceptable under wilderness management objectives, whereas visibility impairment from “unnatural” pollutants and “unnatural” pollution sources is not.

The key to successfully promoting this distinction is an honest and scientific definition of how much, and what types, of fire are “natural” that FLMs, air quality regulators, and the public can agree upon. This is a critical area of future cooperation in smoke management and air quality regulation.

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, very large pollution source. Until recently, the only regulations for visibility protection addressed impairment that is reasonably attributable to a permanent, large emission source or small group of large sources. Recently, EPA issued regional haze regulations to manage and mitigate visibility impairment from the multitude of diverse regional haze sources (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 new rules.

Current data from a national visibility monitoring network (Sisler and others 1996) do not show fire to be the predominant source of visibility impairment in any Class I area (40 CFR Part 51). Emissions from fire are an important episodic contributor to atmospheric loading of visibility-impairing aerosols, including organic carbon, elemental carbon, and particulate matter. Certainly the contribution to visibility impairment from fires can be substantial over short periods of time, but fires in general, occur relatively infrequently and thus have a lesser contribution to long-term averages. Fire events contribute less to persistent visibility impairment than sources with emissions that are more continuous.

Reasonable Progress

The visibility regulations require states to make "reasonable progress" toward the Clean Air Act goal of "prevention of any future, and the remedying of any existing, impairment of visibility…". The regional haze regulations did not define visibility targets, but instead gave the 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 percent of days and 2) ensure no degradation occurs on the clearest 20 percent of days over the period of each implementation plan.

The states are to analyze and determine the rate of progress needed for the implementation period extending to 2018 such that, if maintained, this rate would attain natural visibility conditions by the year 2064. To calculate this rate of progress, the state must compare baseline visibility conditions to estimate natural visibility conditions in Class I areas and determine the uniform rate of visibility improvement that would need to be maintained during each implementation period in order to attain natural visibility conditions by 2064. Baseline visibility conditions will be determined from data collected from a national network of visibility monitors representing all Class I areas in the country for the years 2000 to 2004. The state must determine whether this rate and associated emission reduction strategies are reasonable based on several statutory factors. If the state finds that this rate is not reasonable, it must provide a demonstration supporting an alternative rate.

Regional Visibility Protection Planning

Regional haze is, by definition, from widespread, diverse sources. The regional haze rule encourages states to work together to improve visibility. The Environmental Protection Agency (EPA) has encouraged the 48 contiguous states to engage in regional planning to coordinate development of strategies for controlling pollutant emissions across a multi-state region. This means that groups of states will be addressing groups of "Class I" areas through established organizations. In the West, the Western Regional Air Partnership, sponsored through the Western Governors' Association and the National Tribal Environmental Council is coordinating regional planning and needed technical assessments. In the Eastern U.S., four formal groups address regional planning issues: CENRAP (Central States Response Air Partnership), OTC (Ozone Transport Commission), and VISTAS (Visibility Improvement State and Tribal Association of the Southeast) and the Midwest Regional Planning Organization (figure 4.1.4).

Natural Visibility

Air quality regulations often distinguish between human-caused and natural sources of air pollution. Natural sources of air pollution generally are not responsive to control efforts,

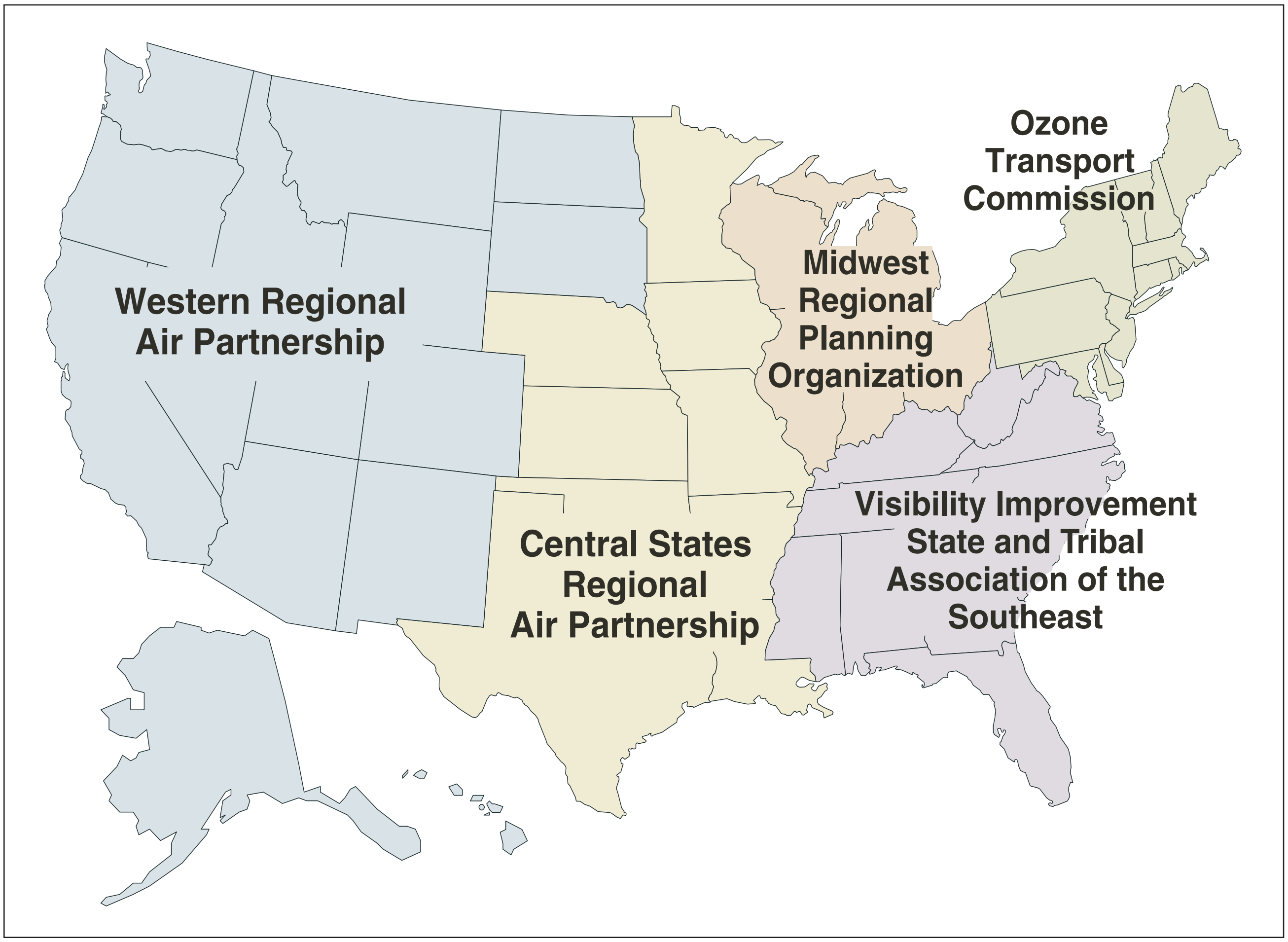


Figure 4.1.4. Regional air quality planning groups.

and state air regulatory agencies manage and monitor them in a manner different from human-caused air pollution. The definition of natural sources of air pollution includes volcanoes, dust, and wildfires. The regional haze regulations propose to measure progress towards achieving natural visibility conditions, but how do we define natural visibility impairment when considering wildland fires as a source?

In most parts of the country, much less fire occurs today than historically. Should natural visibility consider the contribution to haze from these historic, natural fires? And if so, how will we reconcile a definition of natural visibility that includes historic levels of smoke with the need to improve air quality and meet the national visibility goal? Previously, wildfires have been considered natural sources while prescribed fires have generally been classified as human-caused for the purpose of air regulation. That classification is proving to be unsatisfactory because aggressive wildfire suppression and land use changes have made the current pattern of wildfires anything but natural. Are some prescribed fires destined to be categorized as natural emission sources along with the resulting visibility impairment, and how much prescribed burning should be considered natural?

How Much Smoke is Natural?

Few wildlands in the United States are without significant modification by humans, whether by resource utilization, fire suppression, or invasion of exotic species. So in defining natural emissions some possible definitions of natural fire may include: 1) historic fire frequency in vegetation types present on wildlands today, 2) historic fire frequency only on wildlands where the current overriding management goal is to maintain natural ecosystem processes, 3) human-defined fire needed on wildlands to maintain natural ecosystem processes, 4) human-defined fire needed to maximize wildfire controllability, and 5) prescribed fire needed to minimize the sum of prescribed fire and wildfire emissions.[6]

Most any approach to estimating natural emissions from fire will look to historic fire frequencies for preliminary guidance. Historic fire frequency can be defined in numerous ways and called by various terms (fire frequency, fire return interval, natural fire rotation, ecological fire rotation). Fire frequency can vary greatly by vegetative cover type, site-specific meteorology, stand age, aspect, and elevation. Fire frequency is often defined as a range that reflects site variation. For example, a given area of ponderosa pine ecosystem may have a defined fire rotation of 7 to 15 years. The drier southwestern slopes will have an average fire rotation of approximately 7 years, whereas the northern slopes will have an average fire rotation of approximately 15 years. Even within the average site fire rotation interval there can be significant temporal variation depending on weather and ignition potential.

Any change in fire frequency will eventually be expressed by change in the ecosystem. The natural fire regime for an ecosystem may not be the same as the historic fire regime, because neither the current fuel condition nor the climate is the same as in the past. Nor will they be the same in the future.

Wildland fire is highly variable in place and time. Historic fire regimes are well known and described for most major ecosystem types. These historic frequencies can be used as a starting point for definition of natural emissions although, in many parts of the country,historic fire frequency would likely result in much more emissions than would be acceptable in today's society (figure 4.1.5). Prescribed burning in the southeastern US is, in some cases, near the natural rotation and the public has been largely tolerant of the smoke. Burning to maintain natural ecosystem conditions may not need to occur any more frequently than the middle to upper end of the historical average fire frequency. Some areas may be maintained adequately even if the infrequent end of the natural fire frequency range is increased although potential long-term effects of this sort of ecological manipulation are uncertain. On the other hand, the environment is not static. Climate change, for example, may change the frequency of fire necessary to maintain any given ecosystem in the future or make retention of the present ecosystem impossible.

Conclusions

Because smoke from fire can cause negative effects to public health and welfare, air quality protection regulations must be understood and followed by responsible fire managers. Likewise, air quality regulators need an understanding of how and when fire use decisions are

[6] Peterson, Janice; Sandberg, David, Leenhouts, Bill. 1998. Estimating natural emissions from wildland and prescribed fire. An unpublished technical support document to the EPA Interim Air Quality Policy on Wildland and Prescribed Fires. April 23, 1998. (Available from the author).

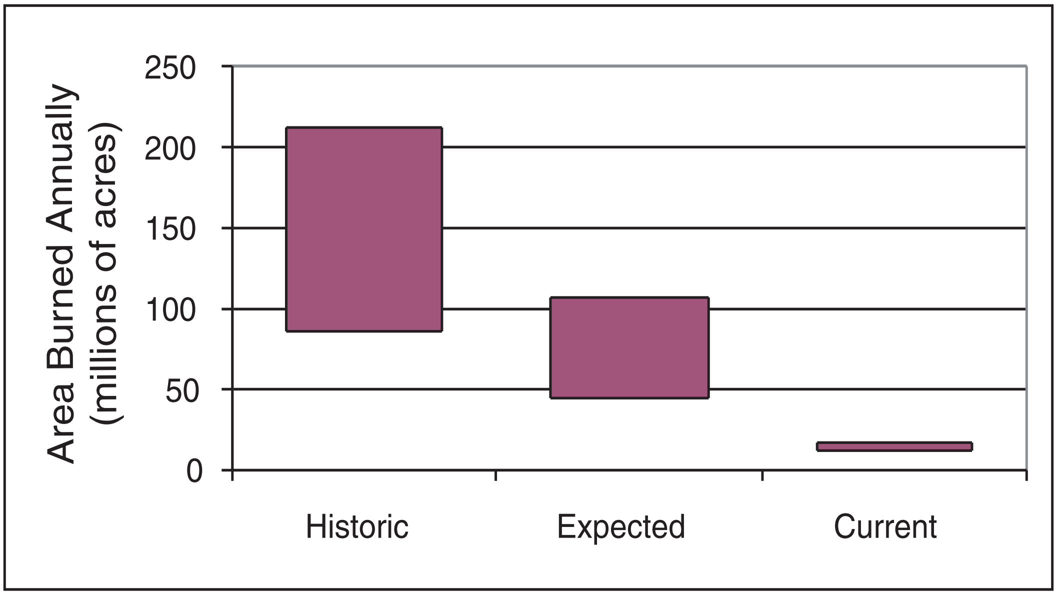


Figure 4.1.5. Estimates of the range of annual area burned in the conterminous United States pre-European settlement (Historic), applying presettlement fire frequencies to present land cover types (Expected), and burning (wildland and agriculture) that has occurred during the recent past (Current). Source: Leenhouts (1998).

Table 4.1.2. Recommended cooperation between wildland fire managers and air quality regulators depending on air quality protection instrument.

Air Quality Protection Instrument	Cooperation[a]	
	Wildland Fire Managers	Air Quality Regulators
NAAQS	Aware	Lead
Attainment Status	Aware	Lead
SIP Planning and Development	Involved	Lead
Conformity	Involved	Lead
Smoke Management Programs	Partner	Lead
Visibility Protection	Involved	Lead
Regional Planning Groups	Partner	Lead
Natural Emissions	Partner	Lead
Natural Events Action Plan (NEAP)	Partner	Lead
Land use planning	Lead	Involved
Project NEPA documents	Lead	Involved
Other Fire Planning Efforts	Lead	Involved

[a] **Lead**: Responsibility to initiate, bring together participants, complete, and implement the particular air quality protection instrument.
Partner: Responsibility to fully participate with Lead organization toward development and implementation of the air quality protection instrument in a nearly equal relationship.
Involved: Responsibility to participate in certain components of development and implementation of the air quality protection instrument although not at full partner status.
Aware: Responsibility to have a complete working knowledge of the air quality protection instrument but likely little or no involvement in it's development or daily implementation.

made and should become involved in fire and smoke management planning processes, including the assessment of when and how alternatives to fire will be used. Many fire and air quality issues need further work including, definition of de minimis emission levels from fire, prescribed fire as BACM for wildfire, clarification of the difference between visibility impairment from fire vs. industrial sources, amounts of smoke from natural ecosystem burning that is acceptable to the public, and definition of natural visibility. Cooperation and collaboration between wildland fire managers and air quality regulators on these and other issues is of great importance. Table 4.1.2 contains recommendations for various types of cooperation by these two groups depending on the applicable air quality protection instrument.

Literature Citations

40 CFR Part 51. Vol. 64 No. 126. Regional Haze Regulations – Final Rule. July 1, 1999.

Dockery DW, Pope CA III, Xu X, Spengler JD, Ware JH, Fay ME, Ferris BG Jr, and Speizer FE. 1993. An association between air pollution and mortality in six U.S. cities. New England Journal of Medicine. 329:1753-1759.

Environmental Protection Agency. 1996. Review of the national ambient air quality standards for particulate matter: policy assessment of scientific and technical information. EPA-452 \ R-96-013. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. Research Triangle Park, NC.

Environmental Protection Agency. 1998. Interim air quality policy on wildland and prescribed fires. Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. 39p.

Leenhouts, Bill. 1998. Assessment of biomass burning in the conterminous United States. Conservation Ecology [online] 2(1). Available from the Internet. URL: http://ns2.resalliance.org/pub/www/journal/vol2/iss1/art1.

Sisler, James F., William C. Malm, Kristi A. Gebhart. 1996. Spatial and seasonal patterns and long term variability of the composition of the haze in the United States: An analysis of data from the IMPROVE network. Cooperative Institute for Research in the Atmosphere, Colorado State University. ISSN: 0737-5352-32.

Trijonis, J., R. Charlson, R. Husar, W. C. Malm, M. Pitchford, W. White. 1991. Visibility: existing and historical conditions - causes and effects. In: Acid Deposition: State of Science and Technology. Report 24. National Acid Precipitation Assessment Program.

Ward, Darold E.; Hardy, Colin C. 1991. Smoke emissions from wildland fires. Environmental International, Vol 17:117-134.

Williamson, Samuel J. 1973. Fundamentals of air pollution. Reading, Massachusetts: Addison-Wesley Publishing Co. 472 p.

U.S. Laws, Statutes, etc.; Public Law 95-95. Clean Air Act as Amended August 1977. 42 U.S.C. 1857 et seq.

U.S. Laws, Statutes, etc.; Public Law 101-549. Clean Air Act as Amended Nov. 1990. 104 Stat. 2399.

State Smoke Management Programs

John E. Core

Introduction

Smoke management programs establish a basic framework of procedures and requirements for managing smoke from prescribed fires. The purposes of a smoke management program are to minimize smoke entering populated areas, prevent public safety hazards (such as smoke impairment on roadways or runways), avoid significant deterioration of air quality and National Ambient Air Quality Standards (NAAQS) violations, and to avoid visibility impacts in Class I areas. Smoke management is increasingly recognized as a critical component of a state's air quality program for protecting public health and welfare, while still providing for necessary wildland burning. Sophisticated programs for coordination of burning both within a state and across state boundaries are vital to obtain and continue public support of burning programs. States typically develop these programs, with cooperation and participation from stakeholders. Smoke management programs developed through partnerships are much more effective at meeting resource management goals, protecting public health, and meeting air quality objectives.

Usually, either the state or tribal natural resources agency or air quality agency is responsible for developing and administering the smoke management program. Occasionally, a program may be administered by a local agency and apply to a subset of a state. Generally the administering agency will give daily approval or disapproval of individual bums. All burning may be subject to permit, or only burning exceeding an established de minimis level that could be based on projections of acres burned, tons consumed, or emissions. Multi-day burns may be subject to daily reassessment and reapproval to ensure smoke does not violate program goals.

An advanced smoke management program will evaluate individual and multiple bums; coordinate all prescribed fire activities in an area; consider cross-boundary impacts; and weigh burning decisions against possible health, visibility, and nuisance effects.

With increasing use of fire for forest health and ecosystem management, interstate and interregional coordination of burning will be necessary to prevent poor air quality episodes. Every state has unique needs and issues driving development of smoke management programs so a specific program cannot be defined that is applicable to all. State and land manager development of, and participation in, an effective, locally specific smoke management program will go a long way to build and maintain public acceptance of prescribed burning.

EPA Interim Fire Policy - Recommendations on Smoke Management Programs

In the Interim Air Quality Policy on Wildland and Prescribed Fires (EPA 1998), EPA urges State and tribal air quality managers to collaborate with wildland owners and managers to mitigate the air quality impacts that could be caused by the increase of fires managed to achieve resource benefits. The EPA especially urges development and implementation of at least basic smoke management programs when conditions indicate that fires will adversely impact the public. In exchange for states and tribes proactively implementing smoke management programs, EPA intends to exercise its discretion not to redesignate an area as nonattainment if the evidence is convincing that fires managed for resource benefits caused or significantly contributed to violations of the daily or annual $PM_{2.5}$ or PM_{10} standards. Rather, EPA will call on the state or tribe to review the adequacy of the smoke management program in collaboration with wildland owners and managers and make appropriate improvements to mitigate future air quality impacts. The state or tribe must certify in a letter to the EPA Administrator that at least a basic program has been adopted and implemented in order to receive special consideration for NAAQS violations under this policy.

To be certifiable by EPA, a smoke management program should include the following basic components, some of which are the responsibility of the administering agency and some of which are provided by the land manager:

1. Process for assessing and authorizing burns.

   Reporting of burn plan information to administering agency (not mandatory for states to be compliant with EPA recommendations for a certified smoke management program, but is highly recommended especially for fires greater than a predefined de minimis size), including the following information:

   - location and description of the area to be burned,
   - personnel responsible for managing the fire,
   - type of vegetation to be burned,
   - area (acres) to be burned,
   - amount of fuel to be consumed (tons/acre),
   - fire prescription including smoke management components,
   - criteria the fire manager will use for making burn/no burn decisions, and
   - safety and contingency plans addressing smoke intrusions.

2. Plan for long-term minimization of emissions and impacts, including promotion of alternatives to burning and use of emission reduction techniques.

3. Smoke management goals and procedures to be described in burn plans (when burn plan reporting is required):

   - actions to minimize fire emissions,
   - smoke dispersion evaluation,
   - public notification and exposure reduction procedures to be implemented during air pollution episodes or smoke emergencies, and
   - air quality monitoring.

4. Public education and awareness.

5. Surveillance and enforcement of smoke management program compliance.

6. Program evaluation and plan for periodic review.

7. Optional programs (for example, special protection zones or buffers or performance standards).

Smoke Management Programs

Prescribed burning programs across the nation use both emission reduction methods and smoke management techniques (avoidance and dilution) to minimize the impacts of smoke on air quality as well as concerns about public exposure to smoke. The complexity of these programs varies greatly from state to state, ranging from the comprehensive and well-funded programs found in Oregon and Washington to the far simpler program found in Alaska. While the comprehensive programs gather detailed information on all burning activity needed for burn coordination, emission inventory calculation purposes, and to assure compliance with air quality regulations, many prescribed fire practitioners work independently with mainly self-imposed constraints. In most cases, smoke management programs focus primarily on achieving land management objectives. Other issues in priority order are: minimizing public exposure to smoke, achieving and/or maintaining healthful air quality, and achieving emission reductions. Often, emission reductions are only an important side benefit of a burning technique selected for another management purpose. Few existing smoke management programs quantify emission reductions achieved either intentionally or unintentionally. Table 4.2.1 summarizes a few of the features of the smoke management programs. Significantly, only Oregon and Washington have active, on-going programs to calculate pollutant emissions and pollutant emission reductions on a daily basis for each burn. The Utah program has been certified under the EPA Interim Air Quality Policy on Wildland and Prescribed Fire; Nevada and Florida have incorporated the Policy into the design of their programs. Oregon and Washington have adopted special provisions for prescribed burning for forest health restoration purposes. The Oregon program includes an emissions cap and offset program for Eastern Oregon burning. Although most state air agencies estimate annual emissions from land manager records, only those states that calculate emissions on a daily basis, burn-by-burn, are listed as having an emissions calculation program. The adequacy of each program to the specific state situation is not addressed in table 4.2.1. That issue is best addressed by the stakeholders of each program and the citizens of the state.

A summary of smoke management program reporting attributes related to emissions tracking is shown in table 4.2.2.

As an example, in the Colorado program, field personnel collect pre-burn acreage, predominate fuel type and fuel loading information annually before the burning season begins. A generalized emissions estimate is reported on the SASEM output they submit with their permit application (see Chapter 9 for information on SASEM and other models). Post-burn information including acreage actually burned, fuel types, fuel loading, and fuel consumption is collected in the field at the end of the season. If the project is classified as “High Risk for Smoke Impacts,” the central office Program Coordinator compiles the end-of-year acreage actually burned and fuel actually consumed from all cooperating agencies. The program office then uses this information to calculate annual emissions. The program office has no responsibilities related to fuel type data. The Colorado smoke management program is fairly basic compared to some more complex programs, but is appropriate to the specifics of the state burning programs and their potential impacts to air quality.

Table 4.2.1. Smoke Management Program features. Smoke Management programs are periodically reviewed and revised; the features listed here reflect program status in 2001.

State	Full Time Staff [a]	Program Fees [b]	Annual Reporting	Daily Emissions Calculation	Intrastate Coordination	Air Quality Monitoring	Visibility Protection
Alabama	No	None	Yes	No	Informal	No	No
Alaska	No	None	Yes	No	Informal	Some	No
Arizona	Yes	None	Yes	No	Formal	Yes	Yes
California[c]	Yes	Yes	Yes	Yes	Formal	Yes	No
Colorado	Yes	Yes	Yes	Yes	Informal	Some	Yes
Florida	Yes	None	Yes	No	Formal	Yes	No
Idaho/Montana	Yes	Based on Emissions	Yes	No	Formal	Yes	No
Louisiana	No	None	No	No	No	No	No
Mississippi	No	None	No	No	Informal	No	No
Nevada	No	None	Yes	No	Informal	No	No
New Mexico	No	None	Yes	No	Informal	Yes	Considered
NE Region	No	None	No	No	Informal	No	No
North Carolina	No	None	No	No	No	No	No
Oregon	Yes	Based on Acres	Yes	Yes	Formal	Yes	Yes
Tennessee	No	None	No	No	No	No	No
South Carolina	Yes	None	Yes	No	Informal	No	No
Utah	Yes	None	Yes	Yes	Formal	Some	Considered
Washington	Yes	Based on Emissions	Yes	Yes	Formal	Yes	Yes

[a] Full time staff means a position with duties dedicated only to meteorological forecasting and program administration

[b] The Arizona and Utah programs are funded through an MOU with participating agencies rather than acreage/tonnage fees. Other agency programs not funded by fees are supported through state/agency budget allocations.

[c] Each of California's 35 air pollution control districts have a unique smoke management plan. Features reported here exist somewhere in the state but do not necessarily apply statewide.

Table 4.2.2. Selected Smoke Management Program Emission Inventory Reporting Attributes.

State	Area Burned		Fuel Type		Fuel Loading		Fuel Consumption		Emissions	
	Field	Program	Field	Program	Field	Program	Field	Program	Field	Program
Arizona	Pre_d/$Post_d$	$Post_d$	Pre_d/$Post_d$	$Post_d$	Pre_d/$Post_d$	$Post_d$	Pre_d/$Post_d$	$Post_d$	None	$Post_d$
CO-Normal	Pre_a/$Post_a$	None	Pre_a/$Post_a$	None	Pre_a/$Post_a$	None	Pre_a/$Post_a$	None	Pre_a	$Post_a$
CO-High Risk	Pre_a/$Post_d$	None	Pre_a/$Post_d$	None	Pre_a/$Post_d$	None	Pre_a/$Post_d$	None	None	$Post_d$
Montana	Pre_a/Pre_a	$Post_a$	Pre_a	None	Pre_a	None	$Post_a$	None	None	$Post_a$
Florida	Pre_d	$Post_d$	None	None	None	None	None	None	None	None
Michigan	Michigan has no statewide program. Forest Service acreage (only) to be burned is tabulated at the beginning of the season. Actual acreage burned is estimated shortly after project completion and reported to their regional office, which then compiles the data annually.									
New York	Pre_d/$Post_d$	$Post_a$	Pre_a	$Post_a$	Pre_a	None	$Post_a$	None	None	None
Washington	Pre_d/$Post_d$	$Post_d$	Pre_d	None	Pre_a	None	None	$Post_d$	None	$Post_a$

Key to subscripts:

Pre_a ----Pre-burn estimate conducted once **annually** at the beginning of the season.

Pre_d ----Pre-burn estimates made on a **daily** basis.

$Post_a$ ---Post-burn estimates made once **annually** at the end of the season.

$Post_d$ ---Post-burn surveys conducted on a **daily** basis soon after completion.

None---Not applicable or no estimate prepared.

Literature Citations

Environmental Protection Agency. 1998. Interim air quality policy on wildland and prescribed fires. Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. 39p.

Federal Land Management–Special Requirements

Janice L. Peterson

Federal agencies are subject to certain laws and requirements that are not necessarily applicable to states or private entities in the same manner or at all. Federal agencies are required to do long-range planning for management of the lands they manage through numerous agency-specific planning mandates. The National Environmental Policy Act (NEPA) requires Federal agencies to examine and disclose potential impacts of their actions on the environment. The General Conformity regulations require federal agencies to examine the effect of their actions on the ability of a state to reach air quality goals and modify their actions if air quality targets would be delayed. Federal agencies also manage wilderness areas and the Wilderness Act contains language with implications for air quality protection.

Land Management Planning

Each Federal land management agency has some sort of overarching planning mandate. These broad scale, long-term plans define how Federal lands will be managed for many years into the future. For the USDA Forest Service, the National Forest Management Act (NFMA) (Public Law 94-588) requires National Forests to prepare plans for land management that address a long-term planning perspective and provide the opportunity for other agencies and the public to comment on decisions on how these public lands are managed. Forest Plans are to address protection, management, improvement, and use of renewable resources on the National Forests and should "recognize the fundamental need to protect and, where appropriate, improve the quality of soil, water, and air resources." Forest Plans must be updated and revised at least every 15 years and many National Forests are in the process of, or have recently completed this task. Other federal agencies have similar land management planning mandates. For the U.S. Department of the Interior, the Bureau of Land Management has the Integrated Resource Management Plan; the National Park Service has the Resource Management Plan; and the Fish and Wildlife Service has the Comprehensive Conservation Plan.

In some parts of the country, resource management agencies have fairly recently recognized the importance of fire as an ecological process in the maintenance of sustainable ecosystems. Therefore, existing federal land management plans do not always adequately address this topic. Planning revisions provide the opportunity to define and resolve issues that involve wildland fire, its relationship to forest health, and its environmental costs and benefits. Revisions should address the fact that smoke knows no boundaries and alternative management scenarios must be analyzed in this same context.

A Forest Service Example

Forest Plans provide the long-term, big picture view of goals for management of a National Forest. Specific projects are planned at a later date to fit the goals and framework of the Forest Plan and to meet more short term planning horizons. For example, the philosophy of how fire will be used to manage various ecosystems on a National Forest and the general effects of this fire on air quality will be described in the Forest Plan whereas specific prescribed fire projects and specific air quality effects will be defined at a later date. The environmental consequences of specific projects are analyzed through the National Environmental Policy Act (NEPA) planning process.

Recent Forest Service internal guidance[1] advises that air quality status within 100km of the Forest boundary be assessed for attainment/non-attainment status, Class I or Class II, availability of monitoring data, and identification of special smoke sensitive areas (such as airports, hospitals, etc.). The complexity of the subsequent Forest Plan air quality analysis will be determined by what is found in this initial assessment and can range from preparation of a simple emissions inventory and development of standards and guidelines for smoke management if the complexity is low; up to a detailed emissions inventory, standards and guidelines for smoke management including visibility protection, modeling to estimate mitigation benefits and/or consequences, worst case emissions analysis, and identification of possible emissions offsets if complexity is high.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) (Public Law 91-190) directs all federal agencies to consider every significant aspect of the environmental impacts of a proposed action. It also ensures that an agency will inform the public that it has considered environmental concerns in its decision-making process. NEPA does not require agencies to elevate environmental concerns over other appropriate considerations; only that agencies fully analyze, understand, and disclose environmental consequences before deciding to take an action. NEPA is a procedural mandate to federal agencies to ensure a fully informed decision where short- and long-term environmental consequences are not forgotten.

An analysis of possible air quality impacts may be needed in a NEPA analysis if the project:

- raised air quality as a significant issue in scoping[2],
- includes burning,
- includes significant road construction, road use, or other soil disturbing procedures where fugitive dust may be a concern,
- includes significant machinery operation in close proximity to publicly accessible areas,
- may have any impact on air quality in a Class I area,
- may have any impact on sensitive vistas or visibility in a Class I area,

[1] USDA Forest Service. 1999. Draft desk guide for integrating air quality and fire management into land management planning. USDA Forest Service guidance document. Available at: http://www.fs.fed.us/clean/air/

[2] Scoping is the process of determining the issues to be included in NEPA analysis and for identifying any significant issues that will need to be addressed in depth. Scoping requires the lead agency to invite participation of affected Federal, State, and local agencies, any affected Indian tribe, the proponent of the action, and other interested persons (including those who might not be in accord with the action on environmental grounds).

- is in close proximity to a non-attainment area,
- will make a significant amount of firewood available to the public.

The appropriate level of analysis for each project will vary with the size of the project. For example, a small project will likely have a brief analysis and a large project will require a detailed analysis. The complexity and potential effects of the project will determine whether an environmental impact statement (EIS), an environmental assessment (EA), a biological evaluation (BE), or a categorical exclusion (CE) is the appropriate NEPA tool. If an air quality analysis is deemed unnecessary, the NEPA document should state that potential air quality impacts were considered but were determined to be inconsequential. In this case, a justification for this determination must be included.

A project NEPA analysis is where specific environmental effects from specific projects are analyzed and assessed. This process provides a good opportunity for fire managers and air quality regulators to come to a common understanding of how smoke from prescribed fire projects will be managed and reduced. Section 309 of the 1977 Clean Air Act Amendments (Public Law 95-95) gives EPA a role in reviewing NEPA documents and making those reviews public. How actively EPA pursues this role tends to vary between EPA regions and with the complexity and potential environmental risk from the project.

A complete disclosure of air quality impacts in a NEPA document should include the following information:

1. Description of the air quality environment of the project area
2. Description of alternative fuel treatments considered and reasons why they were not selected over prescribed fire.
3. Quantification of the fuels to be burned (areas, tons, types).
4. Description of the types of burning planned (broadcast, piles, understory, etc.).
5. Description of measures taken to reduce emissions and emission impacts.
6. Estimation of the amount and timing of emissions to be released.
7. Description of the regulatory and permit requirements for burning (for example, smoke management permits).
8. Modeled estimates of where smoke could go under certain common and worst case meteorological scenarios and focusing on new or increased impacts on down wind communities, visibility impacts in Class I wildernesses, etc. In some areas and for some fuel types, an appropriate dispersion model is not available. In this situation, qualitative analysis will need to suffice. Qualitative analysis can also be used for simple projects with little risk of air quality impact.

Conformity

> *"No department, agency, or instrumentality of the Federal Government shall engage in, support in any way or provide financial assistance for, license or permit, or approve, any activity which does not conform to a State Implementation Plan."*
>
> Clean Air Act Amendments of 1990

The 1990 Clean Air Act Amendments (Public Law 101-549) require planned federal actions to conform to state or tribal implementation plans (SIPs/TIPs). EPA's General Conformity rule established specific criteria and procedures for determining the conformity of planned federal projects and activities. In so doing, EPA chose to apply general conformity directly to non-attainment and maintenance areas only. EPA continues to consider application of general conformity rules to attainment areas but at present has not done so, although an activity in an attainment area that causes indirect emission increases within a non-attainment area may have to be analyzed for conformity. Federal agencies have the responsibility for making conformity determinations for their own actions.

General conformity rules prohibit federal agencies from taking any action within a non-attainment or maintenance area that causes or contributes to a new violation of air quality standards, increases the frequency or severity of an existing violation, or delays the timely attainment of a standard as defined in the applicable SIP or area plan. If a proposed federal project (non-temporary) were projected to contribute pollution to a non-attainment area the project would likely be canceled or severely modified. Temporary proposed federal projects that could impact a non-attainment area must also pass a conformity determination.

Federal activities must not:

1. Cause or contribute to new violations of any standard.
2. Increase the frequency or severity of any existing violations.
3. Interfere with timely attainment or maintenance of any standard.
4. Delay emission reduction milestones.
5. Contradict SIP requirements.

A conformity determination is required for each pollutant where the total of direct and indirect emissions caused by an agency's actions would equal or exceed conformity de minimis levels (table 4.3.1), or are regionally significant. Regionally significant is defined as emissions representing 10 percent or more of the total emissions for the area.

Table 4.3.1. Particle and carbon monoxide de minimis levels for general conformity.

Pollutant / Attainment level	De minimis level (tons per year)
Non-attainment areas	
CO	100
PM_{10}	
Moderate Non-attainment	100
Serious Non-attainment	70
Maintenance areas	
CO	100
PM_{10}	100

The general conformity rule covers direct and indirect emissions of criteria pollutants or their precursors that are caused by a Federal action, reasonably foreseeable, and can practicably be controlled by the Federal agency through its continuing program responsibility. In general, a conformity analysis is not required for wildland fire emissions at the Forest Plan level because specifics of prescribed fire timing and locations are not known, so at this planning level the reasonably foreseeable trigger is not met. A conformity determination will likely be required at a later date when planning specific projects under NEPA.

Wilderness Act

The Wilderness Act (Public Law 88-157) (and subsequent Acts designating individual Wilderness Areas) was enacted to preserve and protect wilderness resources in their natural condition. Wildernesses are to be administered for "the use and enjoyment of the American people in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas, the preservation of their wilderness character, and for the gathering and dissemination of information regarding their use and enjoyment as wilderness…" Although air quality is not directly mentioned in the Wilderness Act, the Act requires wilderness managers to minimize the effects of human use or influence on natural ecological processes and preserve "untrammeled" the earth and its community of life. Federal agencies have interpreted the goals of the Wilderness Act to mean that wilderness character and ecosystem health should not be impacted by unnatural, human-caused air pollution. Most Class I areas are entirely wilderness although some Class I National Parks contain areas that are not wilderness.

Literature Citations

U.S. Laws, Statutes, etc.; Public Law 88-157. Wilderness Act of Sept. 3, 1964. 78 Stat. 890; 16 U.S.C. 1131-1136.

U.S. Laws, Statutes, etc.; Public Law 91-190. [S. 1075], National Environmental Policy Act of 1969. Act of Jan. 1, 1970. In its: United States statutes at large, 1969. 42 U.S.C. sec. 4231, et seq. (1970). Washington, DC: U.S. Government Printing Office: 852-856. Vol. 83.

U.S. Laws, Statutes, etc.; Public Law 94-588. National Forest Management Act of 1976. Act of Oct. 22, 1976. 16 U.S.C. 1600 (1976).

U.S. Laws, Statutes, etc.; Public Law 95-95. Clean Air Act as Amended August 1977. 42 U.S.C. 1857 et seq.

U.S. Laws, Statutes, etc.; Public Law 101-549. Clean Air Act as Amended Nov. 1990. 104 Stat. 2399.

Chapter 5

SMOKE SOURCE CHARACTERISTICS

Smoke Source Characteristics

Roger D. Ottmar

Whether you are concerned with particulate matter, carbon monoxide, carbon dioxide, or hydrocarbons, all smoke components from wildland fires are generated from the incomplete combustion of fuel. The amount of smoke produced can be derived from knowledge of area burned, fuel loading (tons/acre), fuel consumption (tons/acre), and pollutant-specific emission factors. Multiplying a pollutant-specific emission factor (lbs/ton) by the fuel consumed, and adding the time variable to the emission production and fuel consumption equations results in emission and heat release rates that allow the use of smoke dispersion models (figure 5.1). This section discusses the characteristics of emissions from wildland fire and the necessary inputs to obtain source strength and heat release rate for assessing smoke impacts.

Prefire Fuel Characteristics

Fuel consumption and smoke production are influenced by preburn fuel loading categories such as grasses, shrubs, woody fuels, litter, moss, duff, and live vegetation; condition of the fuel (live, dead, sound, rotten); fuel moisture; arrangement; and continuity. These characteristics can vary widely across fuelbed types (figure 5.2) and within the same fuelbed type (figure

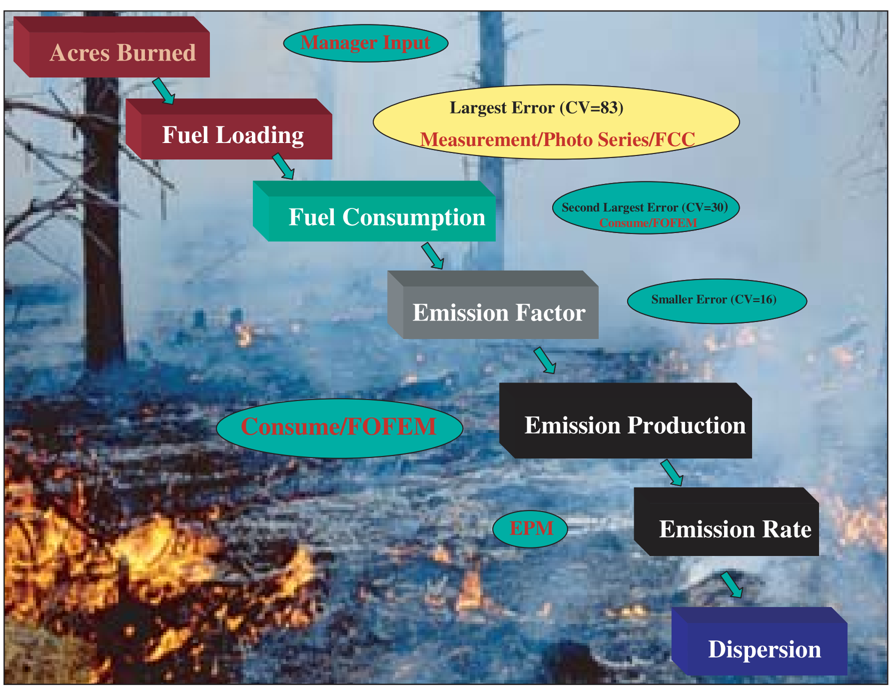


Figure 5.1. Combustion and emission processes.

Figure 5.2. The preburn fuel loading (downed, dead woody, grasses, shrubs, litter, moss, and duff) can vary widely between fuel types as shown in (A) midwest grassland, 2.5 tons/acre; (B) longleaf pine, 4 tons/acre; (C) southwest sage shrubland, 6 tons/acre; (D) California chaparral, 40 tons/acre; (E) western mixed conifer with mortality, 67 tons/acre; and (F) Alaska black spruce, 135 tons/acre.

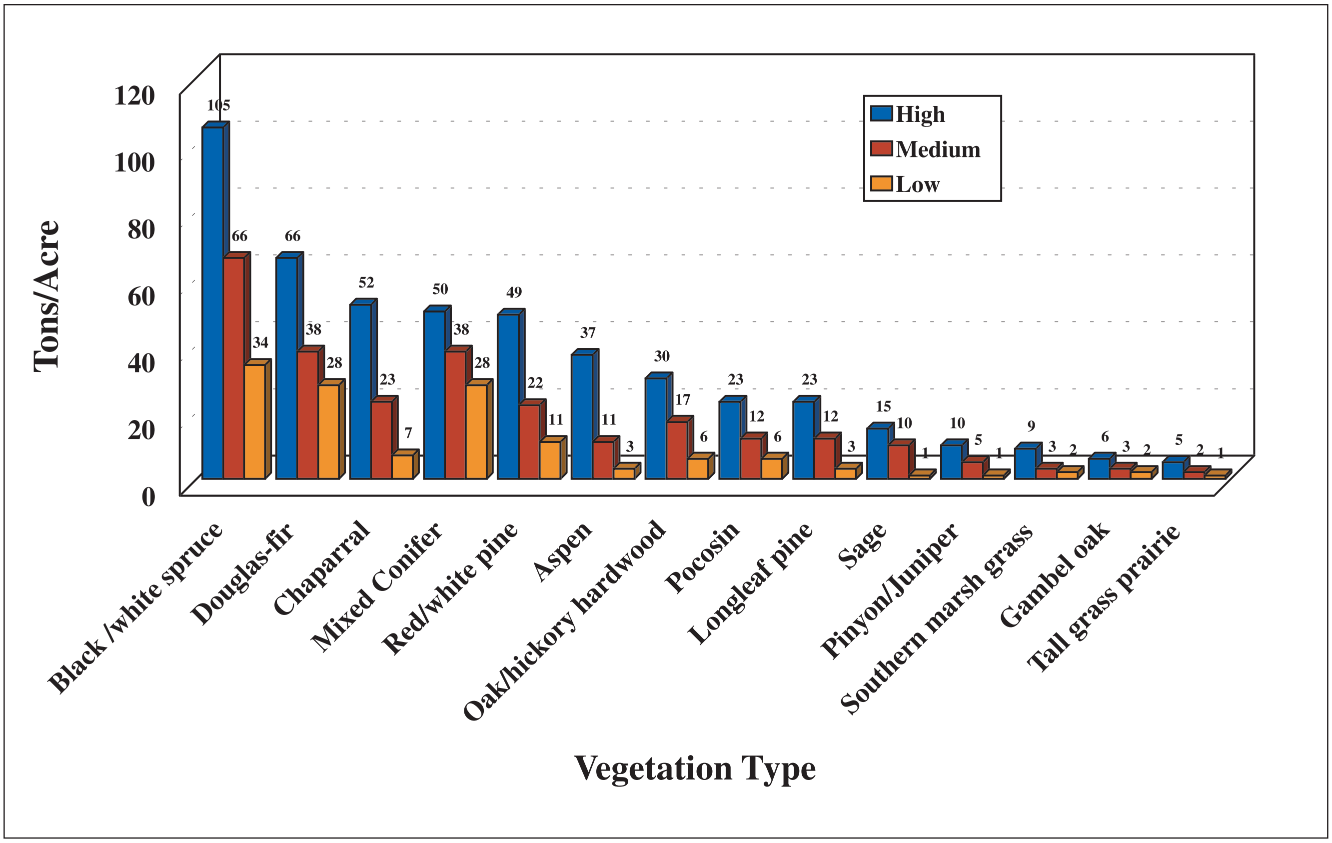


Figure 5.3. Variability of fuel loading across several fuelbed types. Sources are referenced in the text.

5.3). For instance, fuel loadings range considerably: less than 3 tons/acre for perennial grasses in the Midwest with no rotten material or duff (Ottmar and Vihnanek 1999); 4 tons per acre of mostly grass and a shallow litter and duff layers for a southern pine stand treated regularly with fire (Ottmar and Vihnanek 2000b); 6 tons/acre in a Great Basin sage shrubland (Ottmar and others 2000a); 40 tons per acre in a mature California chaparral shrubland (Ottmar and others 2000a); 67 tons per acre of 80 percent of which is rotten woody fuels, stump, snags, and deep duff in a multi-story, ponderosa pine and Douglas-fir forest with high mortality from disease and insects (Ottmar and others 1998); to 167 tons/acre in a black spruce forest in Alaska with a deep moss and duff layer (Ottmar and Vihnanek 1998). The heaviest fuel loadings encountered are normally associated with material left following logging, unhealthy forests, mature brush and tall grasses, or deep layers of duff, moss or organic (muck) soils. The large variation in potential fuel loading can contribute up to 80 percent of the error associated with estimating emissions (Peterson 1987, Peterson and Sandberg 1988).

Higher fuel loading generally equates to more fuel consumption and emissions if the combustion parameters remain constant. For example, a frequently burned southern or western pine stand may have a fuel loading of 12 tons per acre while a recently harvested pine stand with logging slash left on the ground may have a fuel loading of 50 tons per acre. Prescribed burning under a moderately dry fuel moisture situation would achieve 50 percent biomass consumption equating to 3 tons per acre consumed in the unlogged pine stand and 25 tons/acre consumed in the logged stand.

There are several techniques available for determining fuel loading (U.S. Department of Interior 1992). Collecting and weighing the fuel is the most accurate method but is impractical for many fuel types except grasses and small shrubs. Measuring some biomass parameter and estimating the biomass using a pre-derived equation is less accurate but also less time consuming (Brown 1974). Ongoing development of several techniques including the natural fuels photo series (Ottmar and others 1998, Ottmar and Vihnanek 2000a) and the Fuel Characteristic Class system (FCC) (Sandberg and others 2001) will provide managers new tools to better estimate fuel loadings and reduce the uncertainty that currently exist with assigning fuel characteristics across a landscape. The photo series is a sequence of single and stereo photographs with accompanying fuel characteristics. Over 26 volumes are available for logging and thinning slash and natural fuels in forested, shrubland, and grassland fuelbed types throughout the United States. The Fuel Characteristic Class System is a national system being designed for classifying wildland fuelbeds according to a set of inherent properties to provide the best possible fuels estimates and probable fire parameters based on available site-specific information.

Fuel moisture content is one of the most influential factors in the combustion and consumption processes. Live fuel moisture content can vary by temperature, relative humidity, rainfall, soil moisture, seasonality and species. Dead fuel moisture content varies by temperature, relative humidity, rainfall, species, material size, and decay class. Fuel moisture content affects the flame temperature that in turn influences the ease of ignition, the amount and rate of consumption, and the combustion efficiency (the ratio of energy produced compared to energy supplied). In other words, higher fuel moisture content requires more energy to drive off the water, enabling fuel to reach a point where pyrolysis can begin. Generally, fuels with low fuel moisture content burn more efficiently and produce fewer emissions per unit of fuel consumed. On the other hand, even though emissions per unit of fuel burned will be greater at higher fuel moistures because of a less efficient combustion environment, total emissions may be less if some fraction of the fuels do not totally burn—typically the large wood fuels and forest floor.

Since combustion generally takes place at the fuel/atmosphere interface, the time necessary to ignite and consume an individual fuel particle with a given fuel moisture content depends upon the smallest dimension of the particle. The surface area to volume ratio of a particle is often used to depict a particle's size—the greater the ratio, the smaller the particle. Small twigs and branches have a much larger surface to volume ratio than large logs and thus a much greater fuel surface exposed to the atmosphere. Consequently, fine fuels will have a greater probability of igniting and consuming for a given fuel moisture.

The arrangement of the particles is also important. The structuring of fuel particles and air spaces within a fuel bed can either enhance or retard fuel consumption and affect combustion efficiency. The packing ratio (the fraction of the fuel bed volume, occupied by fuel) is the measure of the fuel bed porosity. A loosely packed fuel bed (low packing ratio) will allow plenty of oxygen to be available for combustion, but may result in inefficient heat transfer between burning and adjacent unburned fuel particles. Many particles cannot be preheated to ignition temperature and are left unconsumed. On the other hand, a tightly packed fuel bed (high packing ratio) allows efficient heat transfer between the particles, but may restrict oxygen availability and reduce consumption and combustion efficiency. An efficiently burning fuel bed will have particles close enough for adequate heat transfer while at the same time large enough spaces between particles for oxygen availability.

Fuel discontinuity—both horizontal and vertical—isolates portions of the fuel bed from pre-ignition heating and subsequent ignition. Sustained ignition, and combustion will not occur when the spacing between the fuel particles is too large.

Biochemical differences between species also play a role in combustion. Certain species such as hoaryleaf ceanothus (*Ceanothus crassifolius*), palmetto (*Serenoa repens)* and gallberry (*Ilex glabra*) contain volatile compounds that make them more flammable than species such as Carolina azalea (*Rhododendron carolinianum*) under similar live moisture contents.

Fire Behavior

Fire behavior is the manner in which fire reacts to the fuels available for burning (DeBano and others 1998) and is dependent upon the type, condition, and arrangement of smaller woody fuels, local weather conditions, topography and in the case of prescribed fire, lighting pattern and rate. Two aspects of fire behavior include fire line intensity (the amount of heat released per unit length of fire line) and rate of spread (activity of the fire in extending its horizontal dimensions). These aspects influence combustion efficiency of consuming biomass and the resultant pollutants produced from wildland fires. 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 less smoke. Burning dry grass and shrublands, forestlands with high large woody and duff fuel moisture contents, clean, dry piles, and rapidly igniting an area with circular or strip-head fires will produce these characteristics. In simple, uniform fuelbeds such as pine and leaf litter with only shallow organic material beneath, a backing fire with lower rates of spreads and intensities may consume fuels very efficiently producing less smoke. In more complex fuelbeds, the backing flame may become more turbulent and this combustion efficiency may lessen. 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. Smoldering fires often occur during drought periods in areas with high loadings of large woody material or deep duff, moss, or organic soils. The Emissions Production Model (EPM) (Sandberg and Peterson 1984, Sandberg 2000) and FARSITE (Finney 2000) take into account fire behavior and lighting pattern to estimate emission production rates.

Fuel Consumption

Fuel consumption is the amount of biomass consumed during a fire and is another critical component required to estimate emissions production from wildland fire. Fuels are consumed in a complex combustion process that adds to a variety of combustion products including particulate matter, carbon dioxide, carbon monoxide, water vapor and a variety of various hydrocarbons. Biomass consumption varies widely among fires and is dependent on the fuel type (e.g. grass versus woody fuels), arrangement of the fuel (e.g. piled versus non-piled woody debris), condition of the fuel (e.g. high fuel moisture versus low fuel moisture) and the way the fire is applied in the case of a prescribed fire (e.g. a helicopter or fixed wing aircraft ignited high intensity, short duration mass fire versus a slow, low intensity hand ignition). As with fuel characteristics, extreme variations associated with fuel consumption can contribute errors of 30 percent or more when emissions are estimated for wildland fires (Peterson 1987; Peterson and Sandberg 1988).

In the simplest terms, combustion of vegetative matter (cellulose) is a thermal/chemical reaction where by plant material is rapidly oxidized producing carbon dioxide, water, and heat (figure 5.4). This is the reverse of plant photosynthesis where energy from the sun combines with carbon dioxide and water, producing cellulose (figure 5.4).

In the real world, the burning process is much more complicated than this. Burning fuels is a two-stage process of pyrolysis and combustion. Although both stages occur simultaneously, pyrolysis occurs first and is the heat-absorbing reaction that converts fuel elements such as cellulose into char, carbon dioxide, carbon monoxide, water vapor, and highly combustible hydrocarbon vapors and gases, and particulate matter. Combustion follows as the escaping hydrocarbon vapors released from the surface of the fuels burn. Because combustion efficiency is rarely 100 percent during wildland fires, hundreds of chemical compounds are emitted into the atmosphere, in addition to carbon dioxide and water. Pyrolsis and combustion proceed at many different rates since wildland fuels are often very complex and non-homogeneous (DeBano and others 1998).

It has been recognized that there are four major phases of combustion when fuel particles are consumed (figure 5.5) (Mobley 1976, Prescribed Fire Working Team 1985). These phases are: (1) pre-ignition; (2) flaming; (3) smoldering; and (4) glowing (figure 5.4). During the pre-ignition phase, fuels ahead of the fire front are heated by radiation and convection and 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 begin to decompose, releasing combustible organic gases and vapors (Ryan and McMahon 1976). Since these gases and vapors are extremely hot, they rise and mix with oxygen in the air and ignite at temperatures between 617^0 F and 662^0 F leading to the flaming phase (DeBano and others 1998).

In the flaming phase, the fuel temperature rises rapidly. Pyrolysis accelerates and is accompanied by flaming of the combustible gases and

$$\textbf{CELLULOSE} + \mathbf{O_2} \xrightarrow{\hspace{3em}} \mathbf{CO_2} + \mathbf{H_20} + \textbf{ENERGY}$$

Heat/chemical energy

$$\textbf{CELLULOSE} + \mathbf{O_2} \xleftarrow{\hspace{3em}} \mathbf{CO_2} + \mathbf{H_20} + \textbf{ENERGY}$$

Sun/thermal energy

Figure 5.4. The energy flow for combustion is reverse to that for photosynthesis.

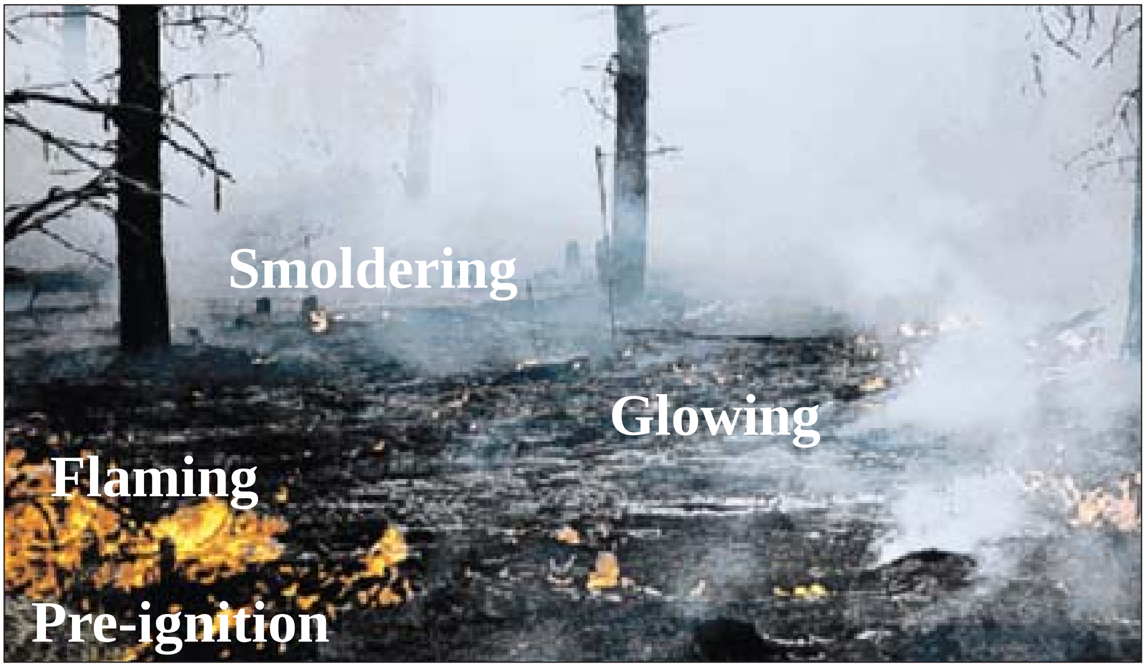


Figure 5.5. The four phases of combustion.

vapors. The combustion efficiency during the flaming stage is usually relatively high as long as volatile emissions remain in the vicinity of the flames. The predominant products of flaming combustion are carbon dioxide (CO_2) and water vapor (H_2O). The water vapor is a product of the combustion process and also derives from moisture being driven from the fuel. Temperatures during the flaming stage range between 932^{0}F to 2552^{0}F (Ryan and McMahon 1976). During the flaming period, the average exterior diameter reduction of round wood material occurs at a rate of 1 inch per 8 minutes (Anderson 1969). For example, a dry limb 3 inches in diameter would take approximately 24 minutes to completely consume if flaming combustion was sustained during the entire time period.

During the smoldering phase, emissions of combustible gases and vapors above the fuel is too low to support a flaming combustion resulting in a fire spread decrease and significant temperature drop. Peak smoldering temperatures range from 572^{o}F to 1112^{o}F (Agee 1993). The gases and vapors condense, appearing as visible smoke as they escape into the atmosphere. The smoke consists mostly of droplets less than a micrometer in size. The amount of particulate emissions generated per mass of fuel consumed during the smoldering phase is more than double that of the flaming phase.

Smoldering combustion is more prevalent in certain fuel types (e.g. 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 area to volume ratios (e.g. grasses, shrubs, and small diameter woody fuels) (Sandberg and Dost 1990). Since the heat generated from a smoldering combustion is seldom sufficient to sustain a convection column, the smoke stays near the ground and often concentrates in nearby valley bottoms, compounding the impact of the fire on air quality.

Near the end of the smoldering phase, the pyrolysis process nearly ceases, leaving the fuel that did not completely consume with a layer of black char, high in carbon content.

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 the 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 (DeBano and others 1998). There is little visible smoke. 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.

The combustion phases occur both sequentially and simultaneously as a fire front moves across the landscape. The efficiency of combustion that takes place in each combustion phase is not the same, resulting in a different set of chemical compounds being released at different rates into the atmosphere. Understanding the combustion process of each phase will assist managers in employing various emission reduction techniques. Fuel type, fuel moisture content, arrangement, and the way the fuels are ignited in the case of prescribed fires, can affect the amount of biomass consumed during various combustion stages. Between 20 and 90 percent of the biomass consumed during a wildland fire occurs during the flaming stage, with the remainder occurring during the smoldering and glowing stages (Ottmar and others [in preparation]. The flaming stage has a high combustion efficiency; that is 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.

Biomass consumption of the woody fuels, piled slash, and duff in forested areas has become better understood in recent years (Sandberg and Dost 1990, Sandberg 1980, Brown and others 1991, Albini and Reinhardt 1997, Reinhardt and others 1997, Ottmar and others 1993, Ottmar and others [in preparation]). Large woody fuel consumption generally depends on moisture content of the woody fuel and duff. Approximately 50 percent of the consumption occurs during the flaming period. Duff consumption depends on fire duration of woody fuels and duff moisture content. Consumption occurs primarily during the smoldering stage when duff moisture is low. Consumption of tree crowns in forests and shrub crowns in shrublands are poorly understood components of biomass consumption and research is currently underway (Ottmar and Sandberg 2000) to develop or modify existing consumption equations for these fuel components.

Since consumption during the flaming phase is more efficient than during the smoldering phase, separate calculations of flaming consumption and smoldering consumption are required for improved assessment of total emissions. Equations for predicting biomass consumption by combustion phase are widely available in two major software packages including Consume 2.1 (Ottmar and others [in preparation]) and First Order Fire Effects Model (FOFEM 5.0) (Reinhardt and Keane 2000).

Consume 2.1 is a revision of Consume 1.0 (Ottmar and others 1993) and uses a set of theoretical models based on empirical data to predict the amount of fuel consumption from the burning of logging slash, piled woody debris, or natural forest, shrub, grass fuels. Input variables include the amount of fuel, woody fuel and duff moisture content, and meteorological data. The software product incorporates the original Fuel Characteristic System (Ottmar and others [in preparation]) for assigning default fuel loadings.

It also incorporates features that allow users to receive credit for applying fuel consumption reduction techniques. FOFEM 5.0 (Reinhardt and Keane 2000) is a revision of FOFEM 4.0 (Reinhardt and others 1997) and relies on BURNUP. a new model of fuel consumption (Albini and Reinhardt 1997). The software computes duff and woody fuel consumption for many forest and rangeland systems of the United States. Both Consume 2.1 and FOFEM 5.0 packages are updated on a regular basis as new consumption models are being developed.

Smoke Emissions

The chemistry of the fuel as well as the efficiency of combustion governs the physical and chemical properties of the resulting smoke from fire. Although smoke from different sources may look similar to the eye, it is often quite different in terms of its chemical and physical properties. Generally, the emissions we cannot see are gas emissions and the emissions we can see are particulate emissions.

Carbon dioxide and water—Two products of complete combustion during fires are carbon dioxide (CO_2) and water (H_2O) and generally make up over 90 percent of the total emissions from wildland fire. Under ideal conditions complete combustion of one ton of forest fuels requires 3.5 tons of air and yields 1.84 tons of CO_2 and 0.54 tons of water (Prescribed Fire Effects Working Team 1985). Under wildland conditions, however, inefficient combustion produces different yields. Neither carbon dioxide nor water vapor are considered air pollutants in the usual sense, even though carbon dioxide is considered a greenhouse gas and the water vapor will sometimes condense into liquid droplets and form a visible white smoke near the fire. This fog/smoke mixture can dramatically reduce visibility and create hazardous driving conditions.

As combustion efficiency decreases, less carbon is converted to CO_2 and more carbon is available to form other combustion products such as carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides(NOx), and sulfur oxides (SOx), all of which are considered pollutants.

Carbon Monoxide—Carbon monoxide (CO) is the most abundant emission product from wildland fires. Its negative effect on human health depends on the duration of exposure, CO concentration, and level of physical activity during the exposure. Generally, dilution occurs rapidly enough from the source of the fire that carbon monoxide will not be a problem for local citizens unless a large fire occurs and inversion conditions trap the carbon monoxide near rural communities. Carbon monoxide is always a concern for wildland firefighters however, both on the fire line at prescribed fires and wildfires, and at fire camps (Reinhardt and Ottmar 2000, Reinhardt and others 2000).

Hydrocarbons—Hydrocarbons (HC) are an extremely diverse class of compounds containing hydrogen, carbon and sometimes oxygen. Usually, the classes of hydrocarbon compounds are identified according to the number of carbon atoms per molecule. Emission inventories often lump all gaseous hydrocarbons together. Although a majority of the HC pollutants may have no harmful effects, there are a few that are toxic. More research is needed to characterize hydrocarbon production from fires.

Nitrogen Oxides—In wildland fires, small amounts of nitrogen oxides (NOx) are produced, primarily from oxidation of the nitrogen contained in the fuel. Thus the highest emissions of No_x occur from fuels burning with a high nitrogen content. Most fuels contain less than 1 percent nitrogen. Of that about 20 percent is converted to NO_x when burned.

Hydrocarbons and possibly nitrogen oxides from large wildland fires contribute to increased ozone formation under certain conditions.

Particulate Matter—Particulate matter produced from wildland fires limits visibility, absorbs harmful gases, and aggravates respiratory conditions in susceptible individuals (figure 5.6). Over 90 percent of the mass of particulate matter produced by wildland is less than 10 microns in diameter and over 80-90 percent is less than 2.5 microns in diameter (figure 5.7). These small particles are inhalable and respirable. Respirable suspended particulate matter is that proportion of the total particulate matter that, because of its small size has an especially long residence time in the atmosphere and penetrates deeply into the lungs. Small smoke particles also scatter visible light and thus reduce visibility.

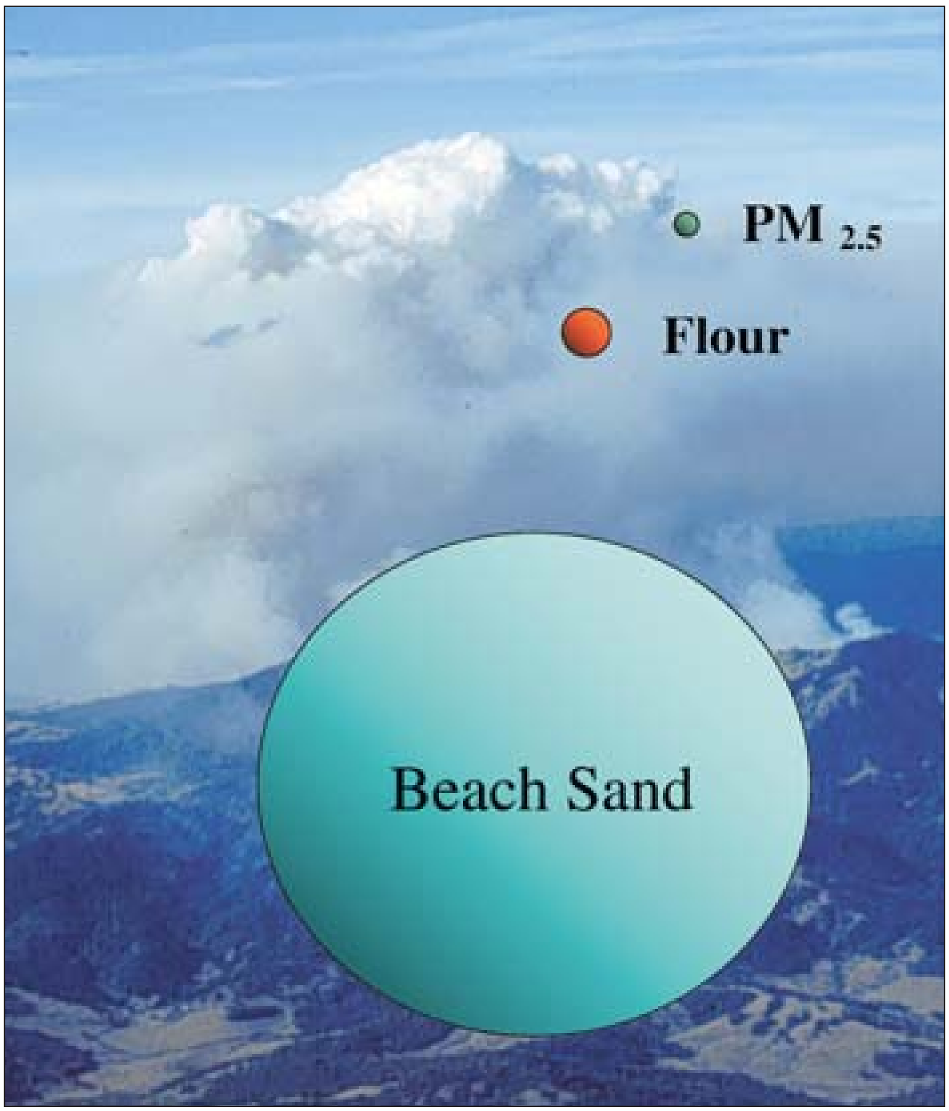


Figure 5.6. Relative sizes of beach sand, flour, and a PM2.5 particle in smoke.

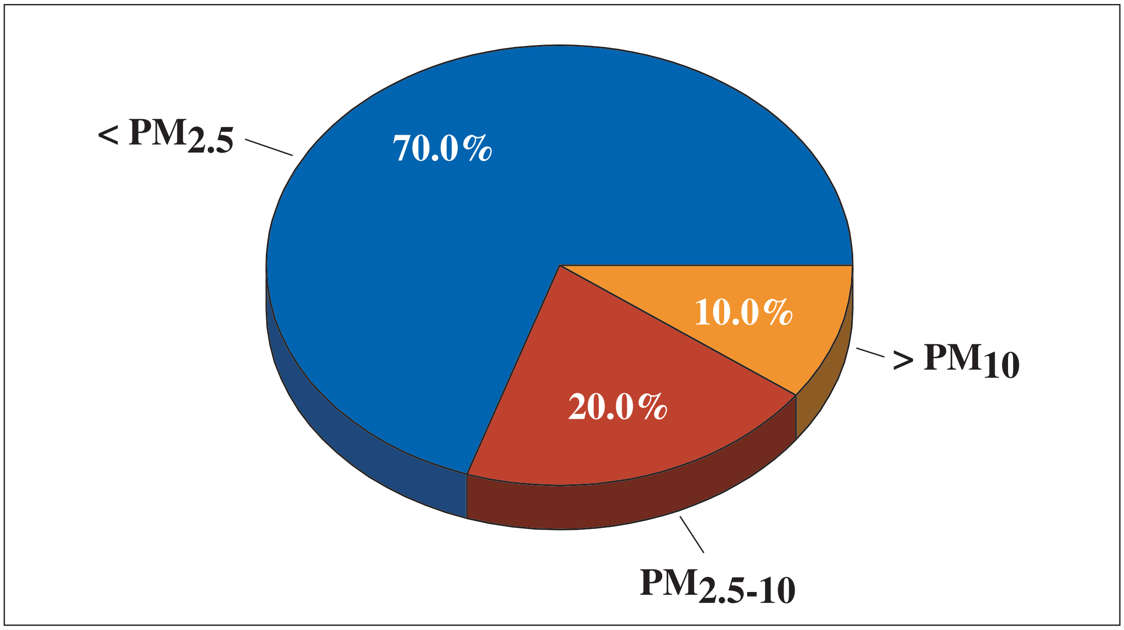


Figure 5.7. Particulate matter size-class distribution from typical wildland fire smoke.

Emission Factors

An emission factor for a particular pollutant of interest is defined as the mass of pollutant produced per mass of fuel consumed (i.e., lbs/ton in the English system or g/kg as the metric equivalent). Multiplying an emission factor in grams/kg by a factor of two will convert the emission factor to English units (pounds/ton).

Emission factors vary depending on type of pollutant, type and arrangement of fuel and combustion efficiency. The average fire emission factors have a relatively small range and contributes approximately 16 percent of the total error associated with predicting emissions production (Peterson 1987; Peterson and Sandberg 1988). In general, fuels consumed by flaming combustion produce less smoke than fuels consumed by smoldering combustion. Emission factors for several smoke compounds are presented in table 5.1 for the flaming, smoldering, and fire average for generalized fuel types and arrangements. Emission factors can be used by air quality agencies to calculate local and regional emissions inventories or by managers to develop strategies to mitigate downwind smoke impacts. Additional emission factors have been determined for other fuel types and will be available in the future.

Total Emissions, Source Strength, and Heat Release Rate

Total emissions from a fire or class of fires (that is, a set of fires similar enough to be characterized by a single emission factor) can be estimated by multiplying that emission factor by the biomass consumed and an accurate assessment of the total acreage burned. For instance, assume that 10 tons/acre of fuels will be con-

Table 5.1. Forest and rangeland emission factors [1]Ward and others 1989; [2]Hardy and others 1996; [3]Hardy and Einfield 1992).

Fuel or Fire Configuration	Combustion Phase[a]	Emission Factors						
		PM	PM_{10}[b]	$PM_{2.5}$	CO	CO_2	CH_4	NMHC
		(Pounds emission per ton fuel consumed)						
BROADCAST BURNED SLASH[1]								
Douglas fir/	FLAMING	24.7	16.6	14.9	143	3385	4.6	4.2
hemlock	SMOLDERING	35.0	27.6	26.1	463	2804	15.2	8.4
	FIRE AVERAGE	29.6	23.1	21.8	312	3082	11.0	7.2
Hardwoods	FLAMING	23.0	14.0	12.2	92	3389	4.4	5.2
	SMOLDERING	38.0	25.9	23.4	366	2851	19.6	14.0
	FIRE-AVERAGE	37.4	25.0	22.4	256	3072	13.2	10.8
Ponderosa/	FLAMING	18.8	11.5	10.0	89	3401	3.0	3.6
l.pole pine	SMOLDERING	48.6	36.7	34.2	285	2971	14.6	9.6
	FIRE AVERAGE	39.6	25.0	22.0	178	3202	8.2	6.4
Mixed conifer	FLAMING	22.0	11.7	9.6	53	3458	3.0	3.2
	SMOLDERING	33.6	25.3	23.6	273	3023	17.6	13.2
	FIRE AVERAGE	29.0	20.5	18.8	201	3165	12.8	9.8
Juniper	FLAMING	21.9	15.3	13.9	82	3401	3.9	5.5
	SMOLDERING	35.1	25.8	23.8	250	3050	20.5	15.5
	FIRE AVERAGE	28.3	20.4	18.7	163	3231	12.0	10.4
PILE-AND BURN SLASH[1]								
Tractor-piled	FLAMING	11.4	7.4	6.6	44	3492	2.4	2.2
	SMOLDERING	25.0	15.9	14.0	232	3124	17.8	12.2
	FIRE AVERAGE	20.4	12.4	10.8	153	3271	11.4	8.0
Crane-piled	FLAMING	22.6	13.6	11.8	101	3349	9.4	8.2
	SMOLDERING	44.2	33.2	31.0	232	3022	30.0	20.2
	FIRE AVERAGE	36.4	25.6	23.4	185	3143	21.7	15.2
"Average" Piles	FIRE AVERAGE	28.4	19.0	17.1	169	3207	16.6	11.6
BROADCAST-BURNED BRUSH[2]								
Sagebrush	FLAMING	45.0	31.8	29.1	155	3197	7.4	6.8
	SMOLDERING	45.3	29.6	26 4	212	3118	12.4	14.5
	FIRE-AVERAGE	45.3	29.9	26.7	206	3126	11.9	13.7
Chaparral	FLAMING	31.6	16.5	13.5	119	3326	3.4	17.2
	SMOLDERING	40.0	24.7	21.6	197	3144	9.0	30.6
	FIRE AVERAGE	34.1	20.1	17.3	154	3257	5.7	19.6
WILDFIRES FIRES (IN FORESTS)[3]								
	Fire-average		30.0	27.0				

[a]Fire Average values are weighted-averages based on measured carbon flux.

[b]PM_{10} values are calculated, not measured, and are derived from known size-class distributions of particulates using PM and $PM_{2.5}$.

sumed during a 200 acre landscape prescribed burn in a ponderosa pine stand. Following the fire, ground surveys and aerial reconnaissance indicate a mosaic fire pattern and only 100 acres of the 200 acres within the fire perimeter actually burned. Since the emission factor for particulate matter 2.5 microns in diameter or less ($PM_{2.5}$) for pine fuels is approximately 22 lbs/ton, then total emission production would be:

$$\underset{\text{(lbs)}}{\text{Total Emissions}} = \underset{\text{(tons/acre)}}{\text{Fuel Consumed}} \times \underset{\text{(lb/ton)}}{\text{Emission Factor}} \times \underset{\text{(acres)}}{\text{Area Burned}}$$

Therefore: $10\,tons/acre * 22\,lbs/ton * 100\,acres \Rightarrow 22{,}000\,lbs \Rightarrow 11\,tons$

Managers can make better estimates of emissions produced from a wildland fire if the amount of fuel consumption in the flaming and smoldering combustion period is known. The same general approach is used although it is slightly more complicated. The fuel consumed during the flaming period and smoldering period are multiplied by the appropriate flaming and smoldering emission factor for a particular fuel type, then summed. Computer software such as Consume 2.1 (Ottmar and others [in preparation]) and FOFEM 5.0 (Reinhardt and Keane 2000) use this approach to improve estimates of total emissions produced from wildland fire as compared with the fire average approach. An emission inventory is the aggregate of total emissions from all fires in a given period for a specific geographic area and requires total emissions.

Modeling emissions from wildland fires requires not only total emissions, but also source strength. Source strength is the rate of air pollutant emissions in mass per unit of time or in mass per unit of time per unit of area and is the product of the rate of biomass consumption and an emission factor for the pollutant(s) of interest. Source strength can be calculated by the equation:

$$\underset{\text{(lbs/minute)}}{\text{Source Strength}} = \underset{\text{(tons/acre)}}{\text{Fuel Consumption}} \times \underset{\text{(acre/minute)}}{\text{Rate of Area Burned}} \times \underset{\text{(lb/ton)}}{\text{Emission Factor}}$$

Emission rates vary by fuel loading, fuel consumption, and emission factors. Figure 5.8 graphically depicts general trend differences in emission production rate and total emissions production (area under each curve) for various prescribed fire scenarios. Mechanically treating fuels before burning, mosaic burning, burning under high fuel moisture contents, and burning piles are specific ways emission rates can be reduced to meet smoke management requirements.

The consumption of biomass produces thermal energy and this energy creates buoyancy to lift smoke particles and other pollutants above the fire. Heat release rate is the amount of thermal energy generated per unit of time or per unit of time per unit of area. Heat release rate can be calculated by the equation:

$$\underset{\text{(BTU/minute)}}{\text{Heat Release Rate}} = \underset{\text{(tons/acre)}}{\text{Fuel Consumption}} \times \underset{\text{(acre/minute)}}{\text{Rate of Area Burned}} \times \underset{\text{(BTU/ton)}}{\text{Heat Output}}$$

Both source strength and heat release rate are required by all sophisticated smoke dispersion models (Breyfogle and Ferguson 1996). Dispersion models are used to assess the impact of smoke on the health and welfare of the public in cities and rural communities and on visibility in sensitive areas such as National Parks, Wilderness areas, highways, and airports. The Emissions Production Model (EPM) (Sandberg and Peterson 1984; Sandberg 2000) is the only model that predicts source strength and heat release rate for wildland fires. The EPM software package imports fuel consumption predictions from Consume 2.1 or FOFEM 5.0 and uses ignition pattern, ignition periods, and burn area components to calculate source strength, heat release rate, and plume buoyancy.

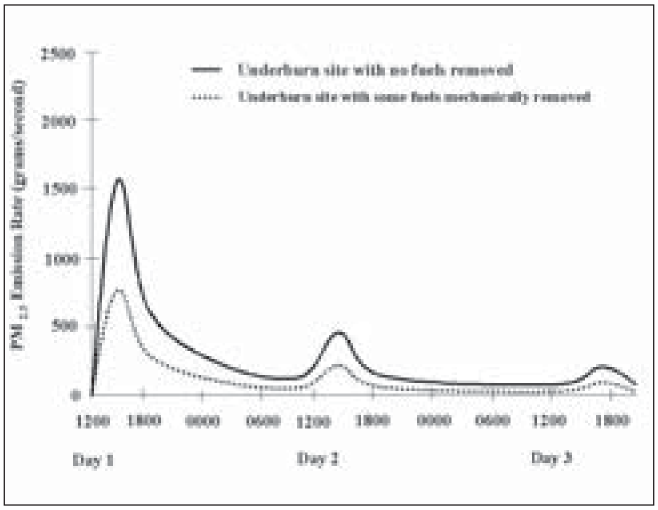


Figure 5.8a. Emission production rate over time for $PM_{2.5}$ during an underburn with and without fuels mechanically removed.

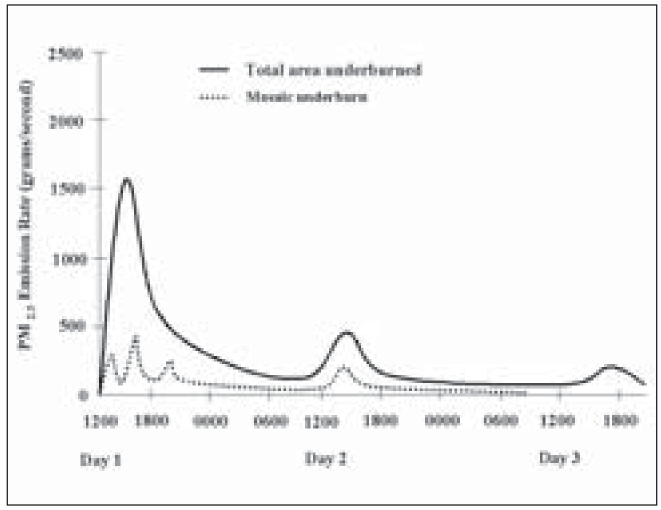


Figure 5.8b. Emission production rate over time for $PM_{2.5}$ during a mosaic burn and a burn where fire covers the entire area within the perimeter.

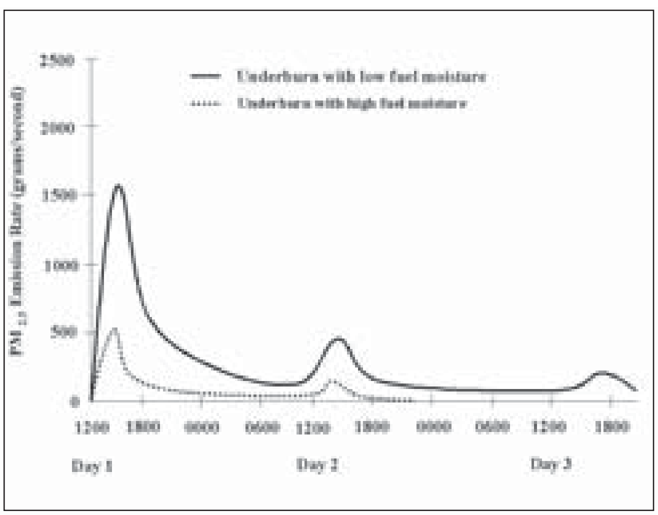


Figure 5.8c. Emission production rate over time for $PM_{2.5}$ during an underburn with low and high fuel moisture content.

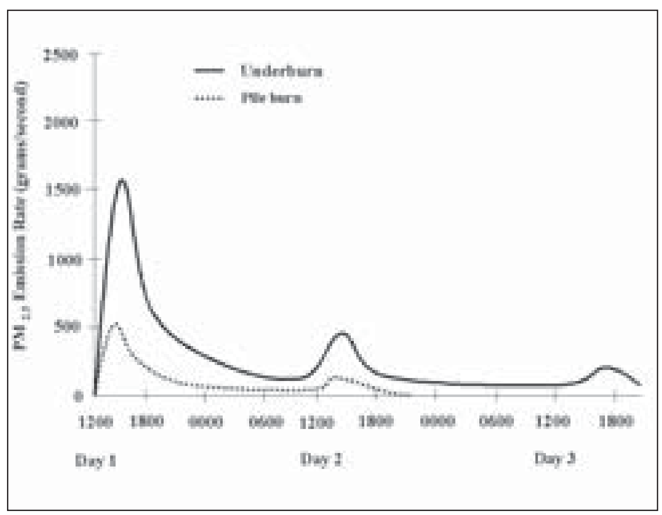


Figure 5.8d. Emission production rate over time for $PM_{2.5}$ during an underburn and a pile burn.

Literature Citations

Agee, James K. 1993. Fire ecology of Pacific Northwest forests. Island Press, Washington D.C. 493 p.

Albini, Frank A.; Reinhardt, Elizabeth D. 1997. Improved calibration of a large fuel burnout model. International Journal of Wildland Fire. 7(1): 21-28.

Anderson, Hal E. 1969. Heat transfer and fire spread. USDA For. Serv. Res. Pap. INT-69, Intermt. For. And Range Exp. Stn., Ogden, UT, 20 p.

Breyfogle, Steve; Ferguson, Sue A. 1996. User assessment of smoke-disperion models for wildland biomass burning. Gen. Tech. Rep. PNW-GTR-379. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 30 p.

Brown, James K. 1974. Handbook for inventorying downed woody material. Gen Tech, Rep. INT-16. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 24 p.

Brown, Jame K.; Reinhardt, Elizabeth D.; Fischer, Wiliam C. 1991. Predicting duff and woody fuel consumption in northern Idaho prescribed fires. Forest Science, Vol. 37, (6): 1550-1566.

Debano, Leonard F.; Neary, Daniel G.; Ffolliott, Peter F. 1998. Fire's effects on ecosystems. New York: John Wiley and Sons, Inc. 333 p.

Finney, Mark. 2000. Personal communication. USDA Forest Service Rocky Mountain Research Station, Fire Laboratory, Missoula, MT.

Hardy, C.C.; Ward, D.E.; Einfield, W. 1992. PM2.5 emissions from a major wildfire using a GIS; rectification of airborne measurements. In: Proceedings of the 29th annual meeting of the Pacific Northwest International Section, Air and Waste Management Association; 1992 November 11-13; Bellevue, WA. Pittsburgh, PA: Air and Waste Management Association.

Hardy, C.C.; Conard, S.G.; Regelbrugge, J.C.; Teesdale, D.T. 1996. Smoke emissions from prescribed burning of southern California chaparral. Res. Pap. PNW-RP-486. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 37p.

Mobley, Hugh E. 1976. Smoke management—What is it? In southern smoke management guide book. Gen. Tech. Rep. SE-10. U.S. Department of Agriculture, Forest Service, Southeast Range and Experiment Station. pp. 1-8.

Ottmar, Roger D.; Burns, Mary F.; Hall, Janet N.; Hanson, Aaron D. 1993. CONSUME users guide. Gen. Tech. Rep. PNW-GTR-304. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 117 p.

Ottmar, Roger D.; Vihnanek, Robert E.; Wright, Clinton S. 1998. Stereo photo series for quantifying natural fuels: Volume I: Mixed-conifer with mortality, western juniper, sagebrush and grassland types in the interior Pacific Northwest. PMS 830. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 73 p.

Ottmar, Roger D.; Vihnanek, Robert E. 1998. Stereo photo series for quantifying natural fuels: Volume II: Black spruce and white spruce types in Alaska . PMS 831. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 65 p.

Ottmar, Roger D.; Vihnanek, Robert E. 1999. Stereo photo series for quantifying natural fuels: Volume V: Midwest red and white pine, northern tallgrass prairie, and mixed oak types in the central and lake states. PMS 834. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 99 p.

Ottmar, Roger D.; Sandberg, David V. 2000. Modification and validation of fuel consumption models for shrub and forested lands in the Southwest, Pacific Northwest, Rockies, Midwest, Southwest, and Alaska. Abstract. Presented at the Joint Fire Science Program Principle Investigators Meeting, October 3-5, 2000, Reno, Nevada. http://www.nifc.gov/joint_fire_sci/jointfiresci.html

Ottmar, Roger D.; Vihnanek, Robert E. 2000a. Photo series for major natural fuel types of the United

States—phase II. Abstract. Presented at the Joint Fire Science Program Principle Investigators Meeting; 2000 October 3-5; Reno, Nevada. http://www.nifc.gov/joint_fire_sci/jointfiresci.html.

Ottmar, Roger D.; Vihnanek, Robert E. 2000b. Stereo photo series for quantifying natural fuels: Volume VI: Longleaf pine, pocosin, and marshgrass types in the southeast United States. PMS 831. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 56 p.

Ottmar, Roger D.; Vihnanek, Robert E.; Regelbrugge, Jon C. 2000a. Stereo photo series for quantifying natural fuels: Volume IV: Pinyon-juniper, sagebrush, and chaparral types in the Southwestern United States. PMS 833. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 97 p.

Ottmar, Roger D.; Reinhardt, Timothy E.; Anderson, Gary, DeHerrera, Paul J. [In preparation]. Consume 2.1 user's guide. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Peterson, Janice L.; Sandberg, David V. 1988. A national PM10 emissions inventory approach for wildfires and prescribed fires. In: Mathai, C.V.; Stonefield, David H., eds. Transactions PM-10 implementation of standards: an APCA/EPA International Specialty Conference; 1988 February 23-24; San Francisco, CA. Pittsburg, PA: Air Pollution Control Association: 353-371.

Peterson, Janice L. 1987. Analysis and reduction of the errors of predicting prescribed burn emissions. Thesis. Seattle: University of Washington. 70 p.

Prescribed Fire and Fire Effects Working Team. 1985. Smoke management guide. PMS 420-2, NFES 1279. Boise ID: National Wildfire Coordinating Group, National Interagency Fire Center. 28 p.

Reinhardt, Elizabeth D.; Keane, Robert E.; Brown, James K. 1997. First Order Fire Effects Model: FOFEM 4.0, users guide. Gen. Tech. Rep. INT-GTR-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 65 p.

Reinhardt, Elizabeth D; Keane, Robert E. 2000. A national fire effects prediction model—revision of FOFEM. Abstract. Joint Fire Science Program Principle Investigators Meeting; 2000 October 3-5, 2000; Reno, Nevada. http://www.nifc.gov/joint_fire_sci/jointfiresci.html

Reinhardt, Timothy E.; Ottmar, Roger D. 2000. Smoke exposure at western wildfires. Res. Pap. PNW-RP-525. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 72 p.

Reinhardt, Timothy E.; Ottmar, Roger D.; Hanneman, Andrew J.S. 2000. Smoke exposure among firefighters at prescribed burns in the Pacific Northwest. Res. Pap. PNW-RP-526. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 45 p.

Ryan, P.W.; McMahon, C.K. 1976. 1976. Some chemical characteristics of emissions from forest fires. In: Proceedings of the 69th Annual Meeting of the Air Pollution Control Association, Portland, OR, Air Pollution Control Association, Pittsburgh, PA. Paper No. 76-2.3.

Sandberg, David V. 1980. Duff reduction by prescribed unferburning in Douglas-fir. USDA For. Serv. Res. Pap. PNW-272. 18 p.

Sandberg, David V. 2000. Implementation of an improved Emission Production Model. Abstract. Joint Fire Science Program Principle Investigators Meeting; 2000 October 3-5; Reno, NV. http://www.nifc.gov/joint_fire_sci/jointfiresci.html.

Sandberg, David V.; Dost, Frank N. 1990. Effects of prescribed fire on air quality and human health. In: Natural and Prescribed Fire in the Pacific Northwest edited by John D. Walstad, Steven R Radosevich, David V. Sandberg. Orgon State University Press, Corvallis, Oregon. 191-218.

Sandberg, David V.; Ottmar, Roger D. 2001 Characterizing fuels in the 21st century. International Journal of Wildland Fire, 10: 381-387.

Sandberg, D.V.; Peterson, J.L. 1984. A source strength model for prescribed fires in coniferous logging slash. Presented to the 1984 Annual Meeting, Air Pollution Control Association, Pacific Northwest Section. Reprint #84.20. Portland, Oregon: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 10 p.

U.S. Department of Interior. 1992. Fire monitoring handbook. San Francisco: U.S. Department of Interior, National Park service, Western Region. [Pages unknown].

Ward, D.E.; Hardy, C.C.; Sandberg, D.V.; Reinhardt, T.E. 1989. Part III-emissions characterization. In; Sandberg, D.V.; Ward, D.E.; Ottmar, R.D., comp. eds. Mitigation of prescribed fire atmospheric pollution through increased utilization of hardwoods, piled residues, and long-needled conifers. Final report. U.S. DOE, EPA. Available from: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Seattle WA.

Chapter 6

FIRE USE PLANNING

Fire Use Planning

Tom Leuschen

Dale Wade

Paula Seamon

The success of a fire use program is in large part dependent on a solid foundation set in clear and concise planning. The planning process results in specific goals and measurable objectives for fire application, provides a means of setting priorities, and establishes a mechanism for evaluating and refining the process to meet the desired future condition. It is an ongoing process, beginning months or even years in advance of actual fire use, with plans becoming increasingly specific as the day of the burn approaches. Although details differ between fire practitioners, the general planning process is essentially the same.

Land and Resource Management Planning

Fire use planning should begin as a component of the overall land and resource management planning for a site. Consideration of the intentional use of fire to achieve stated resource management goals should be an integral part of this process. In deciding whether or not fire use is the best option to accomplish a given objective, an analysis of potential alternative treatments should be completed. This analysis should describe the risks associated with use of a given treatment and include expected negative as well as beneficial outcomes. Care should be exercised to separate statements that are supported by data (preferably local and ecosystem-specific), from those only purported to be true.

Many private landowners do not have written resource management plans, but most have a vision of what natural resource attributes they want to favor and what they want their lands to look like. We recommend they put this vision on paper to provide guidance to themselves and their heirs.

The plans should identify any barriers to implementing a treatment judged best from a resource management standpoint, such as regulations, cost, or insufficient resources. If such a treatment is not recommended because of these barriers, the probable ecological ramifications of this decision should be documented. On sites where fire is selected as the best alternative to accomplish the desired resource management objectives, the next step in fire use planning is to develop a fire management plan.

The Fire Management Plan

The fire management plan addresses fire use at the level of the administrative unit, such as a forest, nature preserve, park, ranch or plantation. It ensures that background information about the area has been researched, legal constraints reviewed, and a burn program found to be both justified and technically feasible. It proposes how fire will be applied to the landscape, both spatially and temporally. When managing for multiple resources (e.g., range, wildlife, and timber) on a tract, guidance should be provided regarding the allocation of benefits; i.e., should benefits to the same resource always be maximized on given burn units, or should the focus be rotated among benefits on some, or all burn units over time?

Items commonly addressed in the fire management plan are:

- Background information on the area, such as topography, soils, climate and fuels
- Applicable fire laws and regulations, including any legal constraints
- Landowner policy governing fire use on this tract of land
- Fire history of the area, including the natural fire regime, and recent fire occurrence or use
- Justification for fire management
- Fire management goals for the area, including a description of the desired future condition. (Objectives for specific burns are set in the burn unit plan, see below.)
- Fire management scheduling, qualitatively describing how fire will be applied to the site over time to achieve stated resource objectives. (Quantitative descriptions of fireline intensity, fire severity, and season of burn are set in the burn unit plan, see below.)
- Species of special concern, wildlife habitat issues, invasive species issues
- Definition and descriptions of treatment units or burning blocks
- Air quality and smoke management considerations
- Neighbor and community factors
- Maps illustrating fuels distribution, treatment units, smoke sensitive areas, etc.

When complete, this document should enable the resource manager to gain the support (both internal and external) and identify the resources needed to effectively and efficiently use fire as a management tool.

Community involvement in the fire planning process is crucial to public acceptance of fire use. At what stage to involve the public in the process will depend on regional issues, regulations, and organizational policy. In general, the earlier the public is involved, the easier it is to reach agreement on any concerns. Whenever it is done, it is important to remember that public support is key to the long-term success of a fire management program. Unexpected results, including under-achievement and over-achievement of objectives, are bound to occur. A full, honest discussion of the potential for such results, and their ramifications, can defuse negative reaction to the occasional bad outcome, especially if the public was involved early in the planning process.

Further guidance for developing a fire management plan is available from a number of federal sources, including *Wildland and Prescribed Fire Management Policy: Implementation Procedures Reference Guide* (USDI and USDA Forest Service 1998), and from The Nature

Conservancy's *Fire Management Manual* (www.tncfire.org/manual).

The Burn Plan

Once the fire management plan is completed and approved, the next step is implementation—not an easy task. Resource managers are usually faced with numerous constraints, such as budget and staff limitations, equipment availability, timing of good burning conditions, and a lack of information on potential effects. A successful prescribed fire program requires the complete dedication of the fire management staff, full cooperation of all personnel and functional areas involved, and unwavering support and commitment throughout the chain of command.

Although the overall resource management goals for an individual burn unit often remain unchanged for long periods, the specific burn objectives for a given unit will likely vary over time, necessitating modifications to the unit plan for each burn. For example, the use of a heading fire during the growing season to promote biodiversity and flowering of ground layer plants may be the current burn objective, while a backing fire during the dormant season may have been used to reduce hazardous fuels loads the last time the unit was burned.

A written burn plan serves several important purposes:

- It makes the planner think about what he/she wants to achieve, and how it will be accomplished.
- It allows the fire manager to prioritize between burn units based on constraints and objectives.
- It functions as the operational plan that details how a burn will be safely and effectively conducted.
- It serves as the standard by which to evaluate the burn.
- It provides a record for use when planning future burns (which makes it essential to document any changes when the burn is conducted, directly on the plan).
- It becomes a legal record of the intended purpose and execution of the burn project.

There is no standard format for a burn unit plan; numerous examples are available which can be consulted for guidance. Sources include state and federal land management agencies, The Nature Conservancy's internet site (www.tncfire.org), or publications such as *A Guide to Prescribed Fire in Southern Forests* (Wade and Lunsford, 1989), which is available online from the Alabama Private Forest Management Team website (www.pfmt.org/standman/prescrib.htm), and from the Florida Division of Forestry (flame.fl-dof.com/Env/Rx/guide/).

Although formats differ, certain components should be included in all burn plans. They should address at least the following 12 topics:

1. **Assessment and Description of the Burn Unit.** The first step in developing a burn plan is to evaluate and document existing conditions. Factors to include depend on the site itself, as well as the complexity of the planned burn. The information recorded here will serve as the baseline from which success of the burn will be determined, so parameters used in the burn objectives should be assessed and described. Include details on the unit size (broken into single-day burn units); date of the last burn; overstory and under-

story vegetation, density and size; fuel type, density and size; soil type and topography; threatened and endangered species present; invasive species present; and current wildlife use.

2. **Maps.** Good maps of the treatment area are a key component of the burn plan. The map scale should be adequate to show pertinent information in meaningful detail. Be careful not to include too much information on a single map, making it difficult to read. The burn plan should include a series of maps showing the following: unit boundaries; adjacent land ownerships, including contact person and phone numbers; topography and manmade obstacles such as canals, ditches, and erosion gullies that would impede equipment or people; natural and constructed fire control lines; areas to be protected or excluded such as sawdust piles, utility poles and sensitive vegetation areas; firing plan; initial placement of equipment and holding personnel, and; escape routes and safety zones. Every crew member should receive a map with the information essential to personnel safety and burn operations.

3. **Measurable Burning Objectives**. Unit-specific treatment objectives identify the desired changes in affected resources from the present to the future condition. Treatment objectives are prepared within the context and intent of all resource management objectives. They are the measures against which the success of a burn is determined. Burn objectives make clear to everyone involved what is expected - including the burners, cooperators, managers, and the public. The objectives should be detailed statements that describe what the treatment is intended to accomplish, and as such, must be specific and quantifiable.

4. **Weather and Fuel Prescription**. The prescription defines the range of conditions under which a fire is ignited and allowed to burn to obtain given objectives. Fuel moisture (by size class) and weather conditions (temperature, humidity, wind, drought, dispersion index) are key factors in achieving objectives because they in large part determine fire behavior (intensity and severity), which in turn, governs ease of fire control and effects. These same parameters also affect smoke production and transport. Considerable care should therefore be taken in defining the window of conditions under which the projected burn may take place. Although there may be an ideal set of conditions that will maximize a single objective, the likelihood of this set of conditions occurring at the right time is typically extremely low. Therefore, a range of fuel and weather conditions are usually specified in the burn prescription that allow the skilled burner to compensate between various parameters to safely and efficiently conduct a successful burn—a burn which meets both the resource and smoke management objectives.

5. **Season and Time of Day**. The season of burn influences many burn parameters. Typically, acceptable burning conditions are more predictable during certain seasons, making it easier to plan and prepare for burns days in advance, but not all burn objectives may be achievable under those weather and fuel conditions. Regional effects are important in decision-making for this factor. For example, in the southeast, dormant season burns are generally more uniform in effects while growing season burns are more likely to be patchy. Backing fires are much easier to conduct during the dormant season when ground layer herbaceous plants are dead and burn readily, rather than green and succulent

thereby retarding fire spread. In the Pacific Northwest, season of burn can be used to reduce emissions. Broadcast burning of slash in the wet spring has been shown to produce 50% fewer emissions when compared to burning periods in the dry fall (Sandberg and Dost 1990). Selecting the correct season to execute a burn will help maximize the probability of achieving the burn objectives.

The timing of ignition determines whether the burn can be completed and mopped up as scheduled during the burning period. Timing is also important when considering factors such as: when solar radiation will break a nighttime inversion or dissipate any dew which formed during the night, when atmospheric conditions will support adequate transport and dissipation of smoke, when surface winds may develop or change speed or direction, or when a sea breeze front may reach the unit. Experienced burners become familiar with the area, and learn how to factor these time-sensitive influences into their burn plans.

6. **Smoke Management**. Planning a fire use project that has the potential to impact areas sensitive to smoke requires assessment of airshed and meteorological conditions that influence both the movement and concentration of smoke. The expected effects of wind speed and direction, air stability, and nighttime inversions should be specifically outlined. Specific regional issues should be addressed, such as mountainous terrain, fog, or sea breeze effects. This information normally will be developed by fire managers using their personal experience and knowledge of fire behavior, smoke transport and dispersion in the area, along with more formal emissions prediction and dispersion modeling.

Sensitive areas downwind of the burn unit should be identified and plotted on a map. Information such as distance and direction from the burn unit, the nature of the sensitivity, and when the area is considered sensitive should be included. Examples of smoke sensitive areas include Class I areas (generally, international parks, and large national parks and national wilderness areas), nonattainment areas, communities or individual residences, airports, highways, and medical facilities. Several procedures for predicting the potential impact of smoke on sensitive areas are discussed in chapter 9.

Smoke dispersion in areas prone to inversions, such as deep, mountainous valleys, is especially problematic in fire use planning. If the smoke remains trapped by the inversion, all of the emissions produced will remain trapped within the airshed.

The following smoke-related questions should be addressed in every plan:

- What quantity of emissions will it take to saturate this airshed?
- Where will the smoke concentrate if it settles under an inversion?
- Do special arrangements need to be made to protect populations impacted by these emissions?
- How many burning projects will it take cumulatively to exceed acceptable levels within this airshed?
- How long will the airshed remain stable and harbor the emissions?

In instances where a burn may affect an area especially sensitive to smoke, the use of air quality monitors may be advisable to ensure that an agreed-upon emission level or limit is not exceeded. Factors to consider in using monitors include placement of the device, personnel to operate the instrument, quality checks, data analysis, and provisions for real-time feedback if data is to be used in making a decision to terminate a burn in progress. Monitors are not commonly accessible and are costly to use, so this option is chiefly available to federal and state agencies. Air quality monitoring for evaluating a fire management program is discussed in Chapter 10.

Smoke impacts to fireline personnel should also be considered in a smoke management plan. The burn planner should consider projected exposure when determining the size of the burn crew and the duration of the work shift. More information on smoke exposure to fireline personnel can be found in Chapter 3.4.

Once an analysis of significant factors is complete, the planner should set specific, measurable smoke management objectives for the burn. These may include, for example, minimum visibility standards for roads or viewsheds, and an emissions limit if air quality monitors are to be used. Objectives provide a common understanding for all individuals involved in or affected by the burn, of what constitutes acceptable smoke impacts. They also provide a tool for the burn boss when deciding whether to terminate a fire because of problematic smoke behavior. If the decision is made to terminate a burn because of smoke problems, it should be remembered that direct suppression often temporarily exacerbates smoke problems. If ignition has been completed, the best strategy may be too let the fire burn out.

The amount of air quality analysis required at all levels of fire planning will be influenced by air quality laws and smoke management regulations. Formal state smoke management programs are becoming increasingly common, but are not yet universal. Some states include only regulatory language regarding "nuisance smoke." Complying with all applicable laws and regulations is a basic tenet of conscientious land stewardship, but responsible fire use and air quality planning include looking beyond the requirements of the law. Communities likely to be impacted by a fire-use program should be involved in determining what their threshold of acceptance is for smoke from wildland fire. Thorough attention to smoke management planning can prevent future problems.

7. **Notification of Local Authorities and the Public**. Early development of a notification plan will assist in the necessary communication with local authorities and the public. A wide variety of methods have proven successful, including distribution of pamphlets or flyers, public meetings, newspaper and radio announcements, and Internet postings. The public should be notified well in advance of the proposed burn day, and again within a few days of executing the burn. Generally, there is a list of individuals to be notified on the actual burn day. This list is often unit-specific, and should be included along with telephone numbers in the burn plan.

8. **Environmental and Legal Constraints**. If constraints to the burn plan have not already been addressed in a fire management plan for the entire site, they should be addressed here because they can limit or determine how a burn is implemented. These may include environmental, economic, operational, administrative, and legal constraints.

9. **Operations**. The burn plan must describe in detail how fire will be used. This section of the plan may take any number of formats, but the topics to be addressed include:

   - Safety. What provisions will be made to ensure the safety of the crew?
   - Communications. How will the crew communicate with each other, and with dispatch or emergency support?
   - Equipment and Personnel. What resources are needed to effectively accomplish the burn and how will they be deployed?
   - Fire Lines. What is the width and condition of existing fire lines? How many chains of fireline need to be prepared or cleared? How will this be accomplished?
   - Ignition Pattern and Sequence. How will the burn be ignited? Ignition duration and firing patterns play an important role in production and lofting of emissions. Rapid ignition may reduce consumption, therefore emissions, and be successful in lofting a smoke column high into the atmosphere. Backing fires produce fewer emissions than heading fires. More information on using ignition to manage emissions production can be found in Chapter 8, Techniques to Reduce Emissions and Impacts.
   - Holding. How will the fire be kept within its predetermined boundaries? How will snags be dealt with?
   - Mop-up. How will the burn be extinguished? What standard will be used to consider the burn unit safe to leave?

10. **Contingency Planning**. Contingency plans outline procedures for dealing with a burn gone awry. They are a normal part of a burn plan and should include provisions to deal not only with escaped fire, but also with unexpected smoke intrusions during an otherwise controlled burn. Some of the issues to be addressed include safety of the general public and the fire crew, sources of assistance for fire control and smoke-related problems, deployment of resources, actions to be taken to rectify the problem, notification of authorities and the public, and measures to mitigate smoke on roadways. It should be recognized that in some cases where smoke problems dictate shutting down a burn after ignition has been completed, the most prudent action may be to allow the unit to burn out rather than to immediately extinguish it, which can temporarily exacerbate smoke production.

11. **Preburn Checklist**. Every burn plan should include a checklist to be reviewed immediately prior to ignition. The checklist should include the factors essential to safe execution of the burn project, and a list of points to review with the crew during the preburn briefing. The use of the checklist ensures that some detail does not slip by the burn manager’s attention in the busy moments preceding a fire.

12. **Monitoring and Evaluation**. Monitoring and evaluation of the burn are key to learning from the process and making refinements for subsequent burns. Where appropriate and practical, monitoring and post-fire evaluation protocols describing the effects on soil, water, air, vegetation, and wildlife should be included in the burn unit plan. Alternatively, the information can be included in a post-burn evaluation report or form, which is attached to the burn plan after completion.

- Documenting air quality conditions before, during, and after a fire is useful in identifying nuisance smoke thresholds and assuring that air quality standards have not been exceeded. Additionally, monitoring and documenting smoke transport, dilution, or concentrations in each airshed can help develop local knowledge that is the basis of predicting smoke impacts. In addition to environmental effects, the following topics should be addressed: adequacy of preburn treatments, fire behavior, degree to which objectives were achieved, discrepancies between planned fuel and weather components and on site measurements, observations, accidents or near-accidents, slopovers, and recommend changes for future burns. A series of photographs over time at permanent photo points is an excellent inexpensive method to document vegetation changes.

Fire Use Planning for Federal Land Managers

The *Wildland and Prescribed Fire Management Policy: Implementation Procedures Reference Guide* (USDI and USDA Forest Service 1998) represents an effort by Federal wildland fire management agencies to establish standardized procedures to guide implementation of the policy described in the 1995 Federal Wildland Fire Management Policy and Program Review. It uses new terminology and definitions to provide consistency and interpretation to facilitate policy implementation, and describes relationships between planning tiers to fire management objectives, products, and applications.

The federal process generally follows the planning process described above. The flow of information begins with the land and resource management plan, variously called the Forest Management Plan (FS), Integrated Resource Management Plan (BIA), Resource Management Plan (NPS), Comprehensive Conservation Plan (FWS) and the Forest Management Plan (FS). This plan determines the availability of land for resource management, predicts levels of resource use and outputs, and provides for a variety of resource management practices.

The next step is preparation of the Fire Management Plan (FMP). The FMP is the primary tool for translating programmatic direction developed in the land management plan into on-the-ground action. The FMP must satisfy NEPA requirements, or follow direction provided by a Forest Plan that has been developed through the NEPA process. Comparisons between fire use activities and no fire use should be described in the NEPA process. This includes implications of wildland fire and prescribed fire use over extended periods of time.

The most detailed step in the process involves the tactical implementation of strategic objectives for the wildland and prescribed fire management programs. It is at this level where specific plans are prepared to guide implementation of fire-related direction on the ground. This step includes Prescribed Fire Plans, Wildland Fire Implementation Plans, and the Wildland Fire Situation Analysis.

More information on the smoke management requirements and federal planning process is contained in Chapter 4.

Literature Citations

Sandberg, D.V.; Dost, F.N. 1990. Effects of prescribed fire on air quality and human health. In: Walstad, John D.; Radosevich, S.R.; Sandberg, D.V., eds. Natural and prescribed fire in Pacific Northwest forests. Corvallis, OR: Oregon State University Press; 191-298.

The Nature Conservancy. 2000. Fire Management Manual. <http://www.tncfire.org/ manual/>.

USDI and USDA Forest Service. 1998. Wildland and prescribed fire management policy—implementation procedures reference guide. National Interagency Fire Center, Boise, ID. 81 p.

Wade, Dale D. and James D. Lunsford. 1989. A guide for prescribed fire in southern forests. Tech. Pub. R8-TP11. Atlanta, GA. USDA Forest Service, Southern Region. 56 p.

Chapter 7

SMOKE MANAGEMENT METEOROLOGY

Smoke Management Meteorology

Sue A. Ferguson

Once smoke enters the atmosphere, its concentration at any one place or time depends on mechanisms of transport and dispersion. By transport, we mean whatever carries a plume vertically or horizontally in the atmosphere. Dispersion simply is the scattering of smoke.

Vertical transport is controlled by the buoyancy of the smoke plume and stability of the atmosphere. Horizontal transport is controlled by wind. The larger the volume of space that smoke is allowed to enter and the farther it can be transported, the more disperse and less concentrated it will become. To begin understanding stability and wind that control transport and dispersion, we begin with a few elemental concepts.

Air Pressure

It is helpful to understand air pressure because storms and stagnant air conditions are described in terms of low pressure and high pressure, respectively. Lines of constant pressure are used to illustrate the state of the atmosphere on weather maps, and pressure influences the expansion and contraction of smoke parcels as they travel through the atmosphere. Air pressure is the force per unit area exerted by the weight of the atmosphere above a point on or above the earth's surface. More simply it can be thought of as the weight of an overlying column of air. Air pressure is greatest near the ground, where the overlying column of air extends the full height of the atmosphere. Pressure decreases with increasing altitude as the distance to the top of the atmosphere shortens.

In a *standard* atmosphere, which represents the horizontal and time-averaged structure of the atmosphere as a function of height only, pressure decreases approximately exponentially with height. With 1,013 millibars (mb) being the standard atmospheric pressure at sea level, the average height of the 850 mb pressure level typically occurs at about 5,000 feet (~1,500 m), the 700 mb pressure level typically occurs at about 10,000 feet (~3,000 m), and the 500 mb height averages around 20,000 feet (~6,000 m). In the lowest part of the atmosphere (less than about 8,000 feet) pressure decreases by approximately 30 mb per 1000 feet. These are useful values to remember when analyzing meteorological data and maps for smoke management. Actual pressure is nearly always within about 30% of standard pressure.

Lapse Rates

Lapse rate is the decrease of temperature with height. Lapse rates help determine whether smoke will rise from a fire or sink back to the surface and are used to estimate atmospheric stability. When air is heated it expands, becomes less dense and more buoyant. This causes it to rise. A parcel of air that is heated at the ground surface by fire or solar radiation becomes warmer than its surroundings, causing it to lift off the surface. As it rises, it encounters lower pressure that causes further expansion. The more air expands, the cooler it becomes. If a parcel of air becomes cooler than its surroundings, it will sink.

Cooling by expansion without an exchange of heat at the parcel boundaries is called adiabatic cooling. In dry air, rising air parcels typically cool at a rate of about 5.5 °F per 1,000 feet (~ 10 °C/km). This is called the dry adiabatic lapse rate (DALR). For example, on a clear day if a heated parcel of air begins at sea level with a temperature of 70 °F (~21 °C), it will cool dry-adiabatically as it rises, reaching a temperature of 53.5 °F (~12 °C) at 3,000 feet (~915 m).

Rising moist air (relative humidity greater than about 70%) is said to undergo a saturation-adiabatic process. The saturated adiabatic lapse rate (SALR) or moist adiabatic lapse rate is a function of temperature and water content. This is because as moist air cools its water vapor condenses, giving off latent heat in the condensation process and causing a saturated parcel to cool more slowly than a dry parcel. Near the ground in mid-latitudes the SALR can be approximated at a rate of about 3 °F per 1,000 feet (~ 5.5 °C/km). For example, on a humid or rainy day, a heated parcel with a 70 °F (~21 °C) initial temperature at sea level, will reach a temperature of 61 °F (~16 °C) at 3,000 feet (~915 m).

Lapse rates are determined by comparing temperatures between different elevations. The temperature from a ridge-top weather station can be subtracted from the temperature at a nearby valley-located weather station to calculate lapse rate. More commonly, radiosonde observations (raobs) are used to determine lapse rates. These balloon-mounted instruments measure temperature, wind, pressure, and humidity at several elevations from the ground surface to thousands of feet. Raobs are available from weather services or at several sites on the Internet twice each day: at 0000 Universal Time Coordinated (UTC)[1] and 1200 UTC.

There are several ways of plotting raob data. Typically a pseudo-adiabatic chart is used. This chart shows measured values of temperature vs. pressure over lines of DALR and SALR. Figure 7.1 illustrates how the above examples would appear on a standard pseudo-adiabatic chart. More recently, skew-T/log-P diagrams (skew-T for short) have become popular. Instead of plotting temperature and pressure on linear, orthogonal axes, skew-T diagrams plot the log of pressure and skew the temperature axis by 45°. The skew-T/log-P view of raob data allows features of the atmosphere to be more obvious than when plotted on a standard pseudo-adiabatic chart. Figure 7.2 illustrates the above examples on a skew-T diagram. On both standard pseudo-adiabatic charts and skew-T diagrams, elevation in meters or feet (corresponding to the pressure of a standard atmosphere) may be shown and wind direction and speed with height is represented parallel to or along the right-hand vertical axis. Many other features also may be included.

Atmospheric Stability

Atmospheric stability is the resistance of the atmosphere to vertical motion and provides an indication of the behavior of a smoke plume. Full characterization of a smoke plume requires a complete estimation of the atmosphere’s turbulent structure that depends on the vertical patterns of wind, humidity, and temperature,

[1] Universal Time Coordinated (UTC) is Standard Time in Greenwich, England. UTC is 9 hours ahead of Alaska Standard Time (AST), where 0000 UTC = 1500 AST and 1200 UTC = 0300 AST. UTC is 5 hours ahead of Eastern Standard Time (EST), where 0000 UTC = 1900 EST and 1200 UTC = 0700 EST.

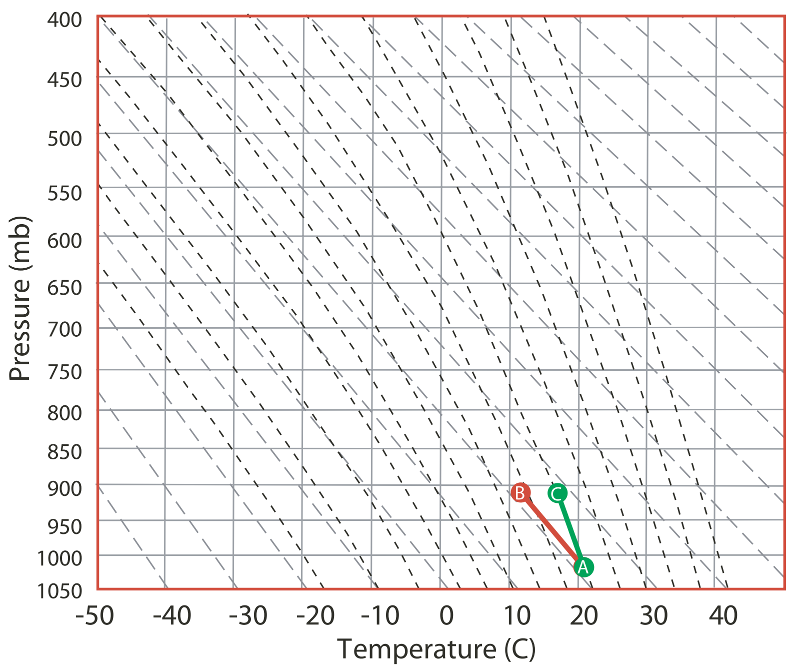


Figure 7.1. Standard pseudo-adiabatic chart. Short-dashed lines show the saturated adiabatic lapse rate (SALR) and long-dashed lines show the dry adiabatic lapse rate (DALR). Point A marks a parcel of air at the surface with a temperature of 21 °C (70 °F). If the atmosphere is dry, the parcel will follow a DALR as it rises and reach point B with a temperature of 12 °C (53.5 °F) at 915m (3000 ft). If the atmosphere is saturated, the parcel will follow a SALR as it rises and reach point C with a temperature of 16°C (61 °F) at 915m (3000 ft).

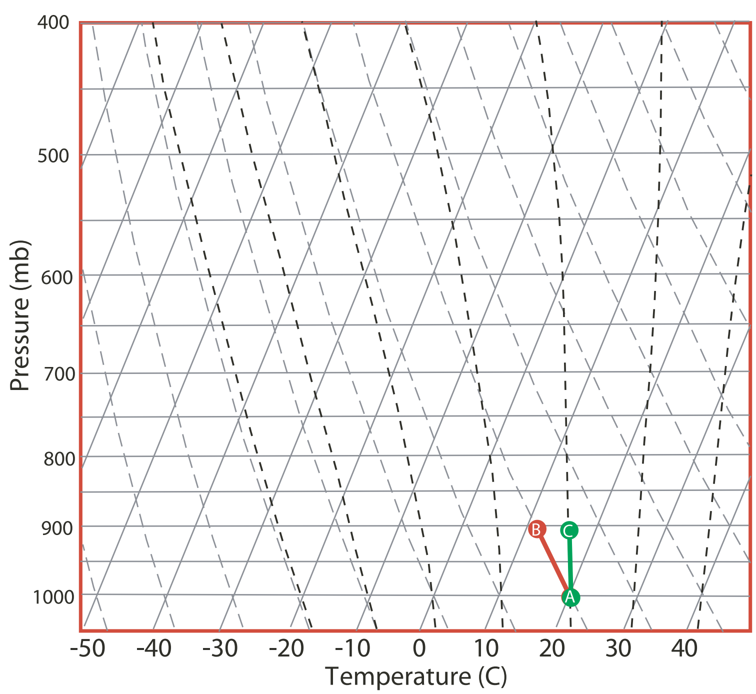


Figure 7.2. Skew-T pseudo-adiabatic chart. Short-dashed lines show the saturated adiabatic lapse rate (SALR) and long-dashed lines show the dry adiabatic lapse rate (DALR). Point A marks a parcel of air at the surface with a temperature of 21 °C (70 °F). If the atmosphere is dry, the parcel will follow a DALR as it rises and reach point B with a temperature of 12 °C (53.5 °F) at 915m (3000 ft). If the atmosphere is saturated, the parcel will follow a SALR as it rises and reach point C with a temperature of 16°C (61 °F) at 915m (3000 ft).

which are highly variable in space and time. Because this can be a complex calculation, it often is approximated by estimates of static stability. The static stability of the atmosphere is determined by comparing the adiabatic lapse rate with ambient, environmental lapse rates (as would be measured from instruments on a rising balloon). By this approximation, an unstable air mass is one in which the temperature of a rising parcel of air remains warmer than its surroundings. In a stable air mass, a rising parcel's temperature is cooler than ambient and a neutral air mass is one in which the ambient temperature is equal to the adiabatic lapse rate.

The most common way of estimating static stability is to note the slope of vertically measured temperature in relation to the slope of the dry (or moist) adiabatic line from a pseudo-adiabatic chart. Figure 7.3 shows raob-measured dry-bulb and dew-point temperatures and the theoretical trajectory of a parcel being lifted from the surface. The parcel trajectory begins at the current surface temperature then follows a DALR until it becomes saturated. The point of saturation is called the lifting condensation level (LCL). Its height in meters can be approximated as 120 x $(T_0 - T_d)$, where T_0 is the temperature at the surface and T_d is the mean dew-point temperature in the surface layers, both in degrees Celsius. From the LCL, the parcel trajectory follows a SALR.

Throughout the depth of the diagram in figure 7.3, the slope of the measured temperature is nearly always steeper than the slope of the adiabatic temperature, suggesting that a lifted parcel always will remain cooler than the ambient temperature, which is a sign of stability. The large distance between the measured temperature and the temperature of the theoretical parcel trajectory also gives an indication of strong

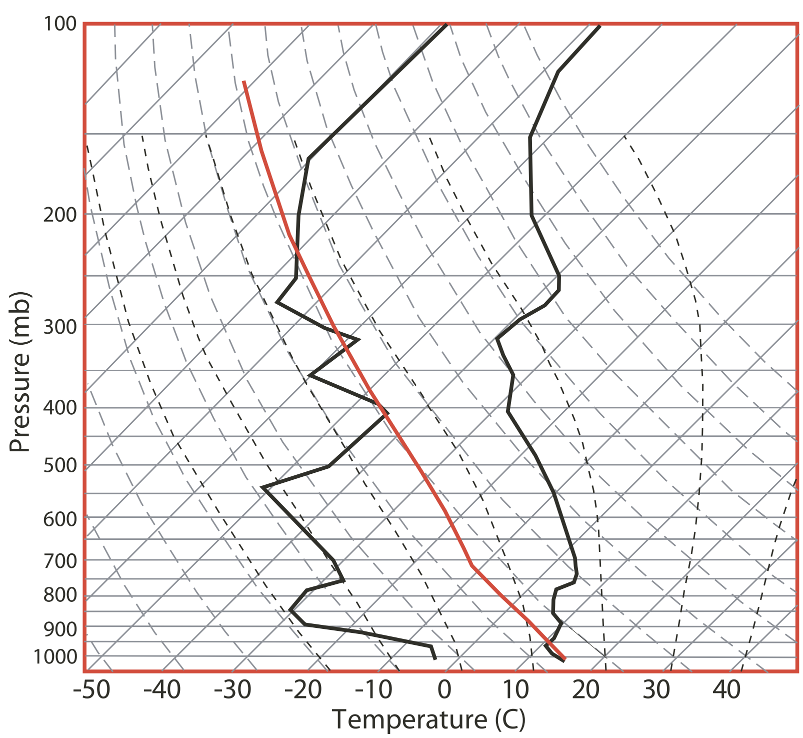


Figure 7.3. Skew-T plot of a stable atmosphere. The thick black line on the right is the measured environmental dry-bulb temperature. The thick black line on the left is the measured environmental dew-point temperature. The red line is a theoretical parcel trajectory. Short-dashed lines are the SALR and long-dashed lines are the DALR.

stability. In a stable atmosphere, smoke emanating from relatively cool fires will stay near the ground. Hot fires may allow plumes to loft somewhat through a relatively stable atmosphere but fumigation of smoke near the ground remains common. Figure 7.4 shows smoke from a vigorous wildfire under a stable atmosphere. Smoke plumes are trying to develop but a strongly stable layer is trapping most smoke just above the ridge tops.

Parcel trajectories in an unstable atmosphere remain warmer than the measured environmental temperatures (figure 7.5). During unstable conditions, smoke can be carried up and away from ground level. Downwind of the source the instability causes smoke plumes to develop a looping appearance (figure 7.6). Obviously there are many variations between stable and unstable atmospheres that cause various patterns of lofting, fanning, coning, looping, and fumigation. Each situation shows characteristic signatures on a pseudo-adiabatic chart but some experience may be required to distinguish the subtle differences.

Because upper-air observations and observations from significantly different elevations are not always available, Pasquill (1961 and 1974) developed a scheme to estimate stability from ground-based observations. Not only is this classification system used to estimate plume characteristics; it also is used in many smoke dispersion models as a proxy for atmospheric turbulence. Table 7.1 shows the Pasquill classification criteria as modified by Gifford (1962) and Turner (1961, 1964, 1970). In this example, surface wind is measured at 10 meters above open terrain. With clear skies, the class of incoming solar radiation is considered strong, moderate, or slight if the solar altitude angle is greater than 60°, between 35° and 60°, or less than 35°, respectively. If more than 50 per cent opaque cloud cover is present and the cloud

Figure 7.4. A smoke plume from a vigorous wildfire during stable atmospheric conditions. Photo by Roger Ottmar.

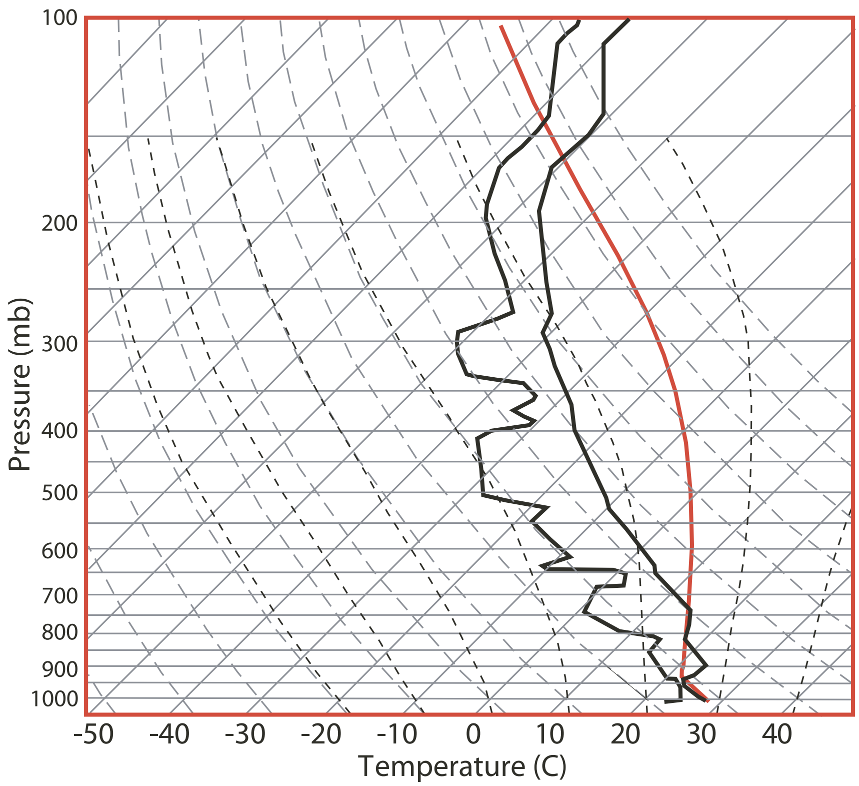


Figure 7.5. Skew-T plot of an unstable atmosphere. The thick black line on the right is the measured environmental dry-bulb temperature. The thick black line on the left is the measured environmental dew-point temperature. The red line is a theoretical parcel trajectory. Short-dashed lines are the SALR and long-dashed lines are the DALR.

Table 7.1. Pasquill stability classification criteria, where A = extremely unstable, B = moderately unstable, C = slightly unstable, D = neutral, E = slightly stable, and F= moderately stable. See text for an explanation of the incoming solar radiation classes.

Surface Wind (m/s)	Daytime Incoming Solar Radiation			Nighttime Cloudiness	
	Strong	Moderate	Slight	≥ 4/8	≤ 3/8
< 2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Figure 7.6. A smoke plume during unstable atmospheric conditions. Photo by Roger Ottmar.

ceiling height is less than 7,000 feet (~2,100m), the solar class is slight. If ceiling height is between 7,000 feet and 16,000 feet (~4,800m), then the solar class is one step below what it would be in clear sky conditions. At night, classification is based on the amount of sky that is obscured by clouds. An objective way of determining stability classification is shown in Lavdas (1986) and Lavdas (1997).

Mixing Height

Mixing height (also called mixing depth) is the height above ground level through which relatively vigorous vertical mixing occurs. Low mixing heights mean that the air is generally stagnant with very little vertical motion; pollutants usually are trapped near the ground surface. High mixing heights allow vertical mixing within a deep layer of the atmosphere and good dispersion of pollutants. As such, mixing heights sometimes are used to estimate how far smoke will rise. The actual rise of a smoke plume, however, considers complex interactions between atmospheric stability, wind shear, heat release rate of the fire, initial plume size, density differences between the plume and ambient air, and radiant heat loss. Therefore, an estimate of mixing height provides only an initial estimate of plume height.

Mixing heights usually are lowest late at night or early morning and highest during mid to late afternoon. This daily pattern often causes smoke to be concentrated in basins and valleys during the morning and dispersed aloft in the afternoon. Average morning mixing heights range from 300 m (~980 ft) to over 900 m (~2,900 ft) above ground level (Holzworth 1972). The highest morning mixing heights occur in coastal areas that are influenced by moist marine air and cloudiness that inhibit radiation cooling at night. Average afternoon mixing heights are typically higher than morning heights and vary from less than 600 m (~2,000 ft) to over 1400 m (~4,600 ft) above ground level. The lowest afternoon mixing heights occur during winter and along the coasts. Mixing heights vary considerably between locations and from day to day.

Ferguson and others (2001) generated detailed maps and statistics of mixing heights in the United States.

Smoke plumes during the flaming stage of fires often can penetrate through weak stable layers or the top of mixed layers. Once the plume dynamics are lost, however, the atmosphere retains control of how much mixing occurs. Low-level smoke impacts increase once a convective column collapses.

The depth of the mixed layer depends on complex interactions between the ground surface and the atmosphere in a region called the planetary boundary layer (PBL). As such, it is difficult to measure exactly and there are many ways in which it is calculated. At times, it is possible to estimate the mixing height by noting the tops of cumulus clouds or the presence of an upper-level inversion, which may appear as a deck of strata-form clouds.

Typically, National Weather Service (NWS) smoke management forecast products will estimate the mixing height by the so-called parcel method. This method considers turbulence related only to buoyancy. When a parcel is lifted adiabatically from the surface, the point at which it intersects the ambient temperature profile, or where it becomes cooler than its surroundings, is the mixing height. Usually the maximum daily temperature is used as the parcel's starting temperature and its adiabatic lapse rate is compared with the afternoon (0000 UTC) sounding profile. Conversely, the minimum daily temperature is used to compare with the morning (1200 UTC) raob for calculating morning mixing heights. If an elevated inversion (see next section) occurs before this height is reached, the height of the inversion base would determine the mixing height. If a surface inversion exists, then its top marks the mixing height. For example, the mixing height in figure 7.3 is at the top of the surface-based inversion at about 750 mb (approximately 2,400 meters or 7,800 feet above ground level).

Instead of approximating a mixing depth, physical calculations of the PBL are possible through numerical meteorological models. These calculations are more precise than the parcel method because they consider turbulence generated by wind shear as well as buoyancy. Each prognostic model, however, may calculate the PBL slightly differently as some functions are approximated while others are explicitly derived to enhance computational efficiency and the vertical resolution, which varies between models, affect PBL calculations.

Temperature Inversions

When the ambient temperature increases with height, an inversion is said to be present. It usually marks a layer of strong stability. When a heated air parcel from the surface encounters an inversion, it will stop rising because the ambient air is warming faster than the expanding parcel is cooling. The parcel being cooler than its surroundings will sink. Although the heat from some fires is enough to break through a weak inversion, inversions often are referred to as lids because of their effectiveness in stopping rising air and trapping pollutants beneath it. Smoke trapped under an inversion can substantially increase concentrations of particles and gases, aggravating respiratory problems and reducing visibility at airports and along roadways.

There are three ways that surface-based inversions typically form: (1) valley inversions are very common in basins and valleys during clear nights when radiation heat losses cause air near the ground to rapidly cool: the cold surface air flows from the surrounding slopes and collects in hollows and pockets, allowing warmer air to remain aloft; (2) advective inversions are caused by cold air moving into a region from a nearby lake or ocean, usually during the afternoon when onshore lake and sea breezes tend to form; and (3) subsidence inversions can occur at any time of day or night as cold air from high altitudes subsides or sinks under a region of relatively stagnant high pressure. Valley inversions cause tremendous problems when managing long-duration fires that continue into the night. Advective inversions can surprise smoke managers who are unfamiliar with local lake- and sea-breeze effects, creating poor dispersal conditions in an afternoon when typically good dispersion is expected. Subsidence inversions are difficult to predict even for a well-trained meteorologist. Figure 7.7 shows smoke caught under a valley inversion that is being transported by down-valley winds in the early morning.

Surface inversions also occur in the gaps (passes and gorges) of mountain ranges. Approaching storms usually have an associated center of low pressure that causes a pressure gradient across the range. If cold air is on the opposite side of the range, the gradient in pressure causes the cold air to be drawn through the gap, creating an inversion in the gap. Gap inversions are most common in winter but also are frequent during spring and autumn.

In addition to surface-based inversions, temperature inversions also occur in layers of the atmosphere that are above the ground surface, which sometimes are called thermal belts. Upper-level inversions usually are associated with incoming warm fronts that bring moisture and warmth to high altitudes well ahead of a storm. The inversion lowers to the ground as the front approaches. Upper-level inversions also may be associated with subsidence or surface-based inversions that have been lifted, usually by daytime heating.

Wind

Not only does smoke mix and disperse vertically, the horizontal component of wind readily transports and disperses pollutants. The stron-

Figure 7.7. A plume of smoke flowing out of a mountain valley with down-slope winds during the early morning. Photo by Roger Ottmar.

ger the wind, the more scattered particles become and the less concentrated they will be. Strong winds at the surface, however, can increase fire behavior and associated emission rates. Also, significant surface winds may "lay-down" a plume, keeping smoke close to the ground for long distances.

Friction with the ground causes winds to slow down. Therefore, wind speed usually increases with height, causing a smoke column to gradually bend with height as it encounters increasingly strong winds. This pattern is complicated in regions of complex terrain, however, and it is common to find stronger surface winds in mountain passes, saddles, and gorges as air is squeezed and funneled through the gap. Forest clearings also allow surface winds to accelerate because surface friction is lower in a clearing than over a forest canopy.

Because smoke from different stages of a fire rises to different levels of the atmosphere, it is important to know wind speed and direction at several different heights. For example, smoldering smoke at night responds to surface winds while daytime smoldering and smoke from the ignition and flaming phase of a fire will respond to upper-level winds. Depending on the buoyancy of the smoke and stability of the atmosphere, winds that influence the upper-level smoke trajectories may be from just above a forest canopy to 10,000 feet (about 3,000 meters) or more. Because flaming heat can create convective columns with strong vertical motion, most smoke during the flaming portion of a fire will be carried to at least the top of the mixing height or an upper-level inversion height before dispersing. In this way, a fire hot enough to pull itself into a single convection column can reduce concentrations near the ground and knowledge of winds at the top of the mixing height or inversion level will determine smoke trajectory and dispersion. Smoldering smoke, on the other hand, has very little forced convection so it often fumigates away from a fire as it rises with daytime buoyancy. Knowledge of wind all the way from the surface to top of the mixing height may be needed to determine smoldering trajectories.

Storm Winds – Storms change the structure of winds entirely. Because storms often bring high instability and good dispersion, it is common to plan fires slightly ahead of an approaching storm. Knowing storm wind patterns can help anticipate associated smoke impacts. Figure 7.8 shows surface wind directions[2] typically associated with a passing cyclonic storm. Because air flows from high pressure to low pressure (like the rush of air from a punctured tire) and storms usually have a center of low pressure at the surface, surface winds ahead of a storm in the northern hemisphere will be from the east or southeast. As the low center approaches, surface winds will become southerly to southwesterly. After the storm passes, surface winds may become more westerly or northwesterly. This pattern can cause smoke to move toward the west to northwest then north to northeast ahead of a cyclonic storm, moving toward the east and southeast following storm passage.

Each cyclonic storm usually contains at least one front (a boundary between two different air masses). A typical storm has a warm front aligned northwest to southeast ahead of the low center, a cold front trailing northeast to southwest near and closely behind the low, and an occluded front (formed when a cold front overtakes a warm front) to the north of the low. Winds change direction most rapidly and become gusty when fronts pass by. Warm fronts can bring increasing stability and cause upper-

[2] Wind direction is the direction from which the wind is blowing. For example, a west wind is coming from the west and blowing toward the east. If you face east, a west wind will hit your back.

level inversions, while cold fronts usually are associated with strong instability. The stronger the front, the more dramatic the wind shift and the stronger the gusts. Cold frontal passage typically improves dispersion of smoke with stronger winds and an unstable air mass that can scour away existing inversions. Smoke trajectories should be expected to change direction with the passage of a storm front and storms can cause significant changes in fire behavior and resulting emission rates. Storm fronts are not always typical, however, and the number, strength, and orientation of fronts are quite variable.

Strong winds above the influence of the earth's surface experience forces associated with the earth's rotation in addition to pressure gradient and other forces. This causes winds in the upper atmosphere to follow lines of constant pressure instead of moving across lines of constant pressure as surface or lower-speed winds do when air flows from high pressure to low pressure. In the upper atmosphere the pressure pattern of a typical storm is shaped like a trough (figure 7.9). As air follows the pressure contours around the trough, southwesterly upper-level winds occur ahead of the storm, becoming westerly as the storm trough passes, and northwesterly following the trough. The upper-level trough usually trails the surface low center in most moving fronts, causing smoke trajectories aloft to change directions sometime after trajectories at the surface have changed following a storm passage.

Thunderstorms, which are the result of strong convection, create much different wind patterns

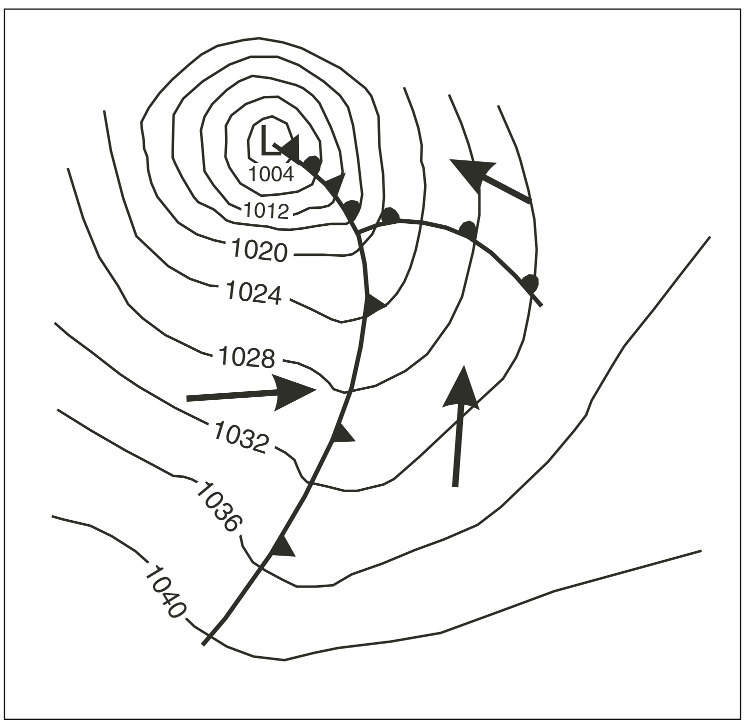


Figure 7.8. Schematic of surface winds associated with a typical cyclonic storm in the Northern Hemisphere. The letter, L, marks position of the surface low pressure center. Thin lines represent isobars (constant pressure contours that are labeled in millibars) at sea level. The thick line marked with barbs represents a surface cold front, marked with half-circles is a warm front, and marked with both is an occluded front. East to southeast surface winds are common ahead of a warm front, south to southwest winds are common ahead of a cold front, and west to northwest winds are common following a cold front.

than cyclonic storms. Gusty, shifty winds are common at times of strong convection. Strong down bursts of wind in a direction away from the thunder cell may occur several minutes ahead the storm, while winds around the cell may be oriented towards it. Although mixing heights usually are quite high during thunderstorms, allowing for well-lofted plumes, the shifting wind directions and strong gusts can cause variable and unpredictable smoke trajectories and fire behavior in close proximity to thunderstorms.

Diurnal Winds – In the absence of storms, diurnal wind patterns dominate trajectories of smoke near the ground. Diurnal patterns are caused by differences between radiational cooling at night and solar heating during the day, and by different thermal properties of land and sea surfaces that cause them to heat and cool at different rates. The differential heating causes changes in surface pressure patterns that control air movement. Slope winds and sea and lake breezes, all of which are common in wildland smoke management situations, typify diurnal patterns.

Slope winds are caused by the same mechanisms that cause valley and basin inversions. When cold air from radiation cooling at night drains into a valley or basin, it causes a downslope wind. The cold air, being denser

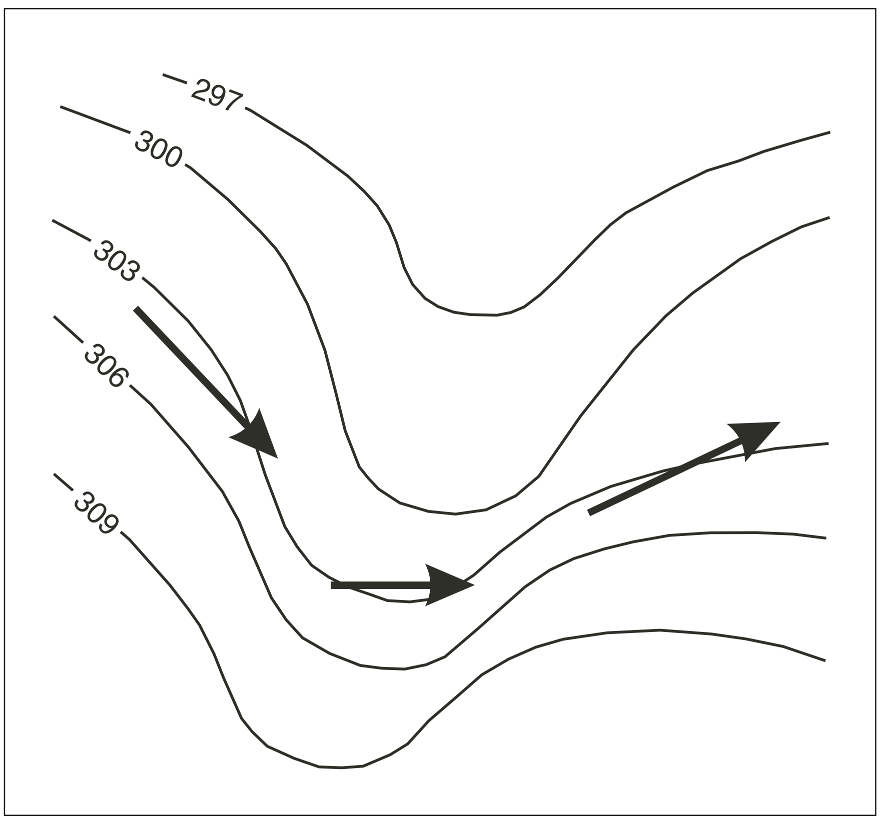


Figure 7.9. Schematic of upper-level (700 mb) winds associated with a typical stormy trough pattern in the Northern Hemisphere. Thin lines represent pressure height contours that are labeled in tens of meters. South to southwest upper-level winds are common ahead of a 700 mb trough, westerly winds are common as the trough passes, and northwesterly winds are common following an upper-level trough.

than its surroundings, usually hugs the terrain in such a way that smoke following a drainage wind will follow contours of the terrain. During the day, heated air from the surface rises, causing upslope winds. Because daytime heating causes more turbulence than nighttime cooling, the daytime winds do not follow terrain as readily as nighttime winds, causing thermally-induced upslope winds to be less noticeable than downslope winds.

Downslope winds at night are notorious for carrying smoke into towns and across roadways (e.g., Achtemeier et al. 1988), especially where roads and bridges cross stream channels or when towns are located in valleys, basins, or near outwash plains. Downslope winds are most likely to occur when skies are clear and ambient winds are nearly calm. The speed and duration of a downslope wind is related to the strength of its associated valley inversion. Downslope winds usually begin around sunset and persist until shortly before sunrise.

Sea and lake breezes usually occur during the afternoon when land surfaces have had a chance to heat sufficiently. The heated air rises, as if lifting the overlying column of air. This causes a region of low pressure at the surface. Because land heats more rapidly than water, the differential heating causes a pressure gradient to form. Relatively cool air remaining over a lake or ocean will flow into the low pressure formed over heated land surfaces. The sea or lake breeze not only can change smoke trajectories but the incoming cool air can cause surface based inversions that will trap smoke at low levels near the ground. Also, strong sea breezes can knock plumes down, causing increasing smoke concentrations near the ground.

Terrain-Influenced Wind – Surface winds are strongly influenced by small undulations in terrain that channel, block, or accelerate air as it tries to move around or over features. For example, if upper-level winds are oriented perpendicular to a terrain barrier, surface winds on the lee side of the barrier often are light and variable. Upper-level winds oriented in the same direction as a valley will enhance upvalley or downvalley winds. Cross-valley winds will be 90° different than those in the valley itself.

The combination of wind and atmospheric stability determine whether smoke will collect on the windward side of a terrain barrier, move up, over and away, or traverse the barrier only to accumulate on the leeward side. Weak winds and a stable atmosphere will enhance blocking and windward accumulations of smoke. Stronger winds in a stable atmosphere may allow accumulations of smoke in leeward valleys and basins. An unstable atmosphere allows smoke to be lifted over and above the terrain. The height, steepness, and orientation of the terrain to the wind direction determine how strong the wind or unstable the atmosphere must be to influence smoke trajectories.

Often very small-scale undulations in topography can affect smoke trajectories, especially at night when atmospheric stability keeps smoke close to the ground. Gentle saddles in ridges may offer outflow of smoke from a valley. Small streambeds can collect and transport significant amounts of smoke even with only shallow or weak downslope winds. A simple band of trees or brush may provide enough barrier to block or deflect smoke. As the urban-wildland interface becomes increasingly complex, the role of subtle topographic influences becomes increasingly important.

Higher in the atmosphere, away from the earth's surface, topography plays a decreasing role in controlling wind speed and direction. Upper-level winds above the influence of underlying terrain are referred to as "free-air" winds and tend to change slowly from one place to another, except around fronts and thunderstorms.

The Role of Inversions on Wind – Temperature inversions significantly influence wind direction and speed. Under many inversions there is little or no transport wind and smoke tends to smear out in all directions. Some inversions, such as advected inversions that are associated with sea breezes and valley inversions, may have significant surface wind but it usually is in a different direction to winds aloft. In these cases, surface smoke may be transported rapidly under the inversion in one direction while lofted smoke may be transported in an opposite direction.

Wind Observations – Because surface winds are strongly influenced by small undulations in terrain, vegetation cover, and proximity to obstacles and water bodies, it is important to know where a surface wind observation is taken in relation to the burn site. For example, observations from a bare slope near the ridgeline will give a poor indication of winds affecting surface smoke trajectories if most of the burn area is on a forested slope or in a valley, even if the two sites are very close. Also, if a burn site is in an east-west oriented valley and the nearest observation is in a north-south oriented valley, observed winds can be 90° different from those influencing the fire and its related smoke. Sometimes, a nearby Remote Automated Weather Station (RAWS) will be less representative of burn-site conditions than one that is farther away if the distant station is in a location that better matches terrain effects expected at the burn site.

There are four principle sources of surface wind data: (1) on-site measurements with a portable RAWS or hand-held anemometer, (2) observations that estimate winds using the Beaufort wind scale[3] or wind sock,[4] (3) local measurements with a standard RAWS, and (4) measurements from NWS observing stations. Because stations vary in their surroundings, from small clearings on forested slopes to open fields, and different types of anemometers are used that are mounted at different heights, wind data is very difficult to compare between one site and another. Therefore, it is useful to become familiar with measurements and observations from reliable sites and understand local effects that make data from that site unique. Also, smoke near the ground can be transported by winds that are too light to spin the cups or propeller of an anemometer or turn its tail. Frequently light and variable wind measurements actually are responding to very light winds that have a preferred direction, often influenced by surrounding topography or land use.

Because free-air winds are above the influence of topography, often it is possible to use an upper-level observation from some point well away from the burn site to estimate upper-level smoke trajectories. Also, surface RAWS that are mounted on the tops of ridges or mountains may compare well with free-air winds at a similar elevation. If clouds are in the area, upper-level winds can be estimated by their movement relative to the ground. High clouds look fibrous or bright white. Because the base of high clouds ranges between 5 km and 13 km (about 16,000 to 45,000 feet) their movement can indicate wind at those high levels. Mid-level clouds may have shades of gray or bulbous edges with bases ranging from 2 km to 7 km (about 6,6000 to 24,000 feet). Mid-level clouds often have a strata-form or layered appearance, which may indicate the presence of an inversion.

[3] The Beaufort wind scale estimates wind speed using observations of wind-effects in the landscape. For example, wind speeds of 1.6 to 3.3 m/s (4 to 7 mph) will cause leaves to rustle slightly. If leaves move around vigorously then the wind speed is approximately 3.4 to 5.4 m/s (8 to 12 mph).

[4] Wind socks continue to be used at airports and are useful if trying to monitor winds on a nearby ridge that is visible.

Therefore, movement of these types of clouds may closely approximate steering winds for a rising smoke plume.

In addition to observations, it is becoming increasingly common to have available the output from wind models. These data do not provide the detail of a point observation the way an individual site measurement does, but they do provide a broad view of wind patterns over the landscape. Standard analyses from the NWS use models to interpolate between observations. These products help illustrate upper-level wind patterns and typically are available for 850 mb, 700 mb, and 500 mb heights, either from a state, federal, or private meteorological service, or a variety of Internet sites. For surface winds, standard NWS analyses are helpful in regions of flat or gently rolling terrain but mesoscale meteorological models typically are needed to resolve surface wind fields in regions of complex topography. Several regions throughout the country are beginning to employ mesoscale models (e.g., MM5, RAMS, and MASS) producing wind maps with less than 15 km horizontal spacing. Local universities, research labs, state offices, and consortia of local, state, and federal agencies have undertaken mesoscale modeling efforts. Output usually can be found on a local Internet site through the NWS forecast office, a fire weather office, university, state regulator, EPA office, or regional smoke manager. Also, many smoke dispersion models have built-in wind models to generate surface winds at very fine spatial resolutions (less than 5 km grid spacings) from inputs of surface and upper-air observations or data from coarser meteorological models. Smoke dispersion models and their related wind models may be available through a regional smoke manager or EPA office (see Chapter 9—Smoke Dispersion Prediction Systems).

Atmospheric Moisture

Because water vapor in the atmosphere reduces visibility, if smoke is added to an already humid environment, visibility can be severely degraded. Also, if the air is saturated with water vapor, particles from smoke may act as condensation nuclei causing water droplets to form. This promotes the formation of clouds or fog, which further degrades visibility. Often a deadly combination occurs during the darkness of night as smoldering smoke drains down-valley to encounter high humidities from condensing cold air under a valley inversion. The effect can be fatal, especially along transportation corridors (Achtemeier and others 1998).

Favorable conditions for fog occur when the dew point temperature is within a few degrees of the dry bulb temperature, wind is less than a few meters per second, and there is a high content of moisture in the soil. Fog is most common at night when temperatures often drop to near the dew point value and winds are most likely to be weak. Common places for fog to form are over lakes and streams and in the vicinity of bogs and marshes.

There are times when atmospheric moisture can improve visibility, however. Smoke particles can adhere to rain droplets, causing them to be carried with the rain as it falls. This "scavenging" effect removes smoke particles out of the atmosphere, reducing smoke concentrations and improving visibility.

Weather Forecasts

Weather forecasts typically are produced twice each day and become available within 3 to 6 hours after 0000 UTC and 1200 UTC observations are complete. This is because prognostic models require input data from the 0000 UTC and 1200 UTC upper-air observations and a few hours of run-time on a super computer. Prognostic models (progs) form the basis of most forecast products. For example, the first forecast of the day should be available by 7 am to 10 am local daylight time from Anchorage and by 10 am to 1 pm local standard time from Miami. Earlier forecasts or forecasts updated throughout the day are possible if the most recently available upper-air observations and prognostic model outputs are combined with updated surface observations. While public forecasts issued by the NWS and the media are useful, they typically lack the detail needed for smoke management. For this reason, spot-weather forecasts may be requested from state, federal, or private weather services that provide predictions of critical variables that influence smoke at specified times and locations.

Even though there are increasing numbers of numerical guidance tools, weather forecasting still is an art, especially in places with few observations or where there are complex local interactions with terrain, water bodies, and vegetation cover. The primary source of smoke weather forecasts remains the National Weather Service. Their rigorous training, fire weather program, and state-of-the art equipment and analysis tools help maintain a unique expertise. Most NWS fire weather forecast offices now issue special dispersion and transport forecasts. In addition to NWS forecasters, many states maintain a smoke management program with highly skilled meteorologists. Also, the number of inter-agency fire weather offices and private meteorological services is growing and can provide reliable forecast products specifically designed for smoke management. Whatever the source of a forecast, it is helpful to combine the forecast with your own general understanding of weather conditions by reviewing the many satellite pictures, current observation summaries, and prognostic model output products now available on the World Wide Web. In this way, apparent trends and local influences can be determined and the need for last minute changes can be recognized more quickly. For example, increasing afternoon cloudiness in the forecast may have indicated an approaching storm that was predicted for the following morning. If clouds do not increase when predicted, however, it could be suspected that the storm has been delayed or it was diverted elsewhere. A check with the forecaster or updated satellite picture may confirm the suspicion and the management plan may be altered.

Because the atmosphere behaves chaotically, the accuracy of a weather forecast improves as time to an event shortens. For example, it is possible to provide an indication of storminess within 30 to 90 days. A storm passage, however, may not be predicted until about 14 days in advance with about 2 days accuracy. Within 5 days, 1-day accuracy on storm passage may be possible. Increasing accuracy should be expected within 48 hours and the timing of storm passage within 1/2 hour may be possible with 12 hours advance notice. Spot weather forecasts usually are available 24 to 48 hours in advance of a scheduled burn. This allows a smoke manager to anticipate a potential burning window well in advance. Specific timing, however, should not be made before 2 days in advance if the situation is highly dependent on an accurate weather forecast.

Our increasing knowledge of air-sea interactions is making it possible to predict some aspects of weather up to a year in advance as certain regions of the country respond to the El Niño Southern Oscillation (ENSO). Precipitation and temperature during winter and spring are most strongly related to ENSO. Relating key factors for smoke management such as wind and mixing height or stability is more difficult, especially during summer. Nevertheless, an ENSO-based seasonal prediction gives prescribed burners an idea of general weather conditions to be expected, thereby helping prioritize scheduled burns and decide if marginal days or weekends early in the burning season should be used or whether a more optimum season will ensue.

Climate

Climate simply describes the prevailing weather of an area. Understanding climate patterns can help develop long-range smoke management plans or adapt short-range plans. For example, afternoon mixing heights in most coastal regions of the United States are typically lower than the interior because moist, marine air is relatively stable. This means that there may be fewer days with optimum dispersion along the coast than interior. It usually is windier along the coast, however, and burns might be scheduled in the early morning if offshore breezes are desired to reduce smoke impacts on cities and towns.

It is possible to infer climate just by local proximity to oceans, lakes, rivers, and mountains. Also, vegetation cover can give an indication of climate. Desert landscapes, with a lot of bare soil or sand, heat and cool rapidly, causing them typically to have high daytime mixing heights and very low nighttime mixing heights. Natural landscapes of lush green forests tend to absorb sunlight while transpiring moisture, both of which help to modify heating and cooling of the ground surface. This can reduce daytime mixing heights and keep nighttime heights relatively high, with respect to deserts. Also, the structural deformation of trees often indicates high winds, where the direction of branches or flagging point away from prevailing wind directions.

Quantitative summaries of climate can be obtained from the state climatologist or Regional Climate Center (RCC), many of whom also maintain informative Internet sites and can be reached through the National Climatic Data Center (NCDC) <www.ncdc.noaa.gov>. It is most common to find temperature and precipitation in climate summaries. Monthly or annual averages or extremes are readily available while climate summaries of daily data are just beginning to emerge. For example, a recently generated climate database by Ferguson and others (2001) provides information on twice-daily variations in surface wind, mixing height, and ventilation index over a 30-year period.

We know that there are year-to-year variations in climate (e.g., ENSO) so at least 10 years of weather data are needed to obtain a preliminary view of climate in a particular area. There also are natural, "decadal" patterns in climate that last from 7 to 20 years. Therefore, it is appropriate to acquire 30 to 50 years of weather observation data for any reliable climate summary.

Summary

Managing smoke in ways that prevent serious impact to sensitive areas from single burns or multiple burns occurring simultaneously requires knowledge of the weather conditions that will affect smoke emissions, trajectories, and dispersion. Not only is it necessary to anticipate the weather ahead of time through the use of climatology and forecasts, but it also is useful to monitor conditions prior to and during the burn with regional, local, and on-site observations. On-site observations are helpful because air movement, and therefore smoke movement, is influenced by small variations in terrain and vegetation cover, and proximity to lakes and oceans, which off-site observations usually cannot capture. Also, forecasts are not always accurate and last-minute changes in a burn or smoke management plan may be needed. To gain more insight into the physical process of weather in wildland areas and its effect on biomass fires, refer to the Fire Weather handbook (Schroeder and Buck 1970).

In using weather observations, forecasts, and climate summaries effectively for smoke management there are 3 general guidelines; (1) become familiar with local terrain features that influence weather patterns, (2) develop a dialogue with a reliable local weather forecaster, and (3) ask for and use climate summaries of wind and mixing height. By combining your knowledge of local weather effects, trust and communication with an experienced forecaster, and understanding of climate patterns, it is possible to fine-tune or update forecasts to meet your specific smoke management needs.

Literature Citations

Achtemeier, G.L., W. Jackson, B. Hawkins, D.D. Wade, and C. McMahon. 1998. The smoke dilemma: a head-on collision! Transactions of the 63rd North American Wildlife and Natural Resource Conference. 20-24 March 1998. Orlando FL. 415-421.

Ferguson, S.A.; S. McKay; D. Nagel; T. Piepho; M.L. Rorig; and C. Anderson. 2001. The potential for smoke to ventilate from wildland fires in the United States. In Proceedings of the 4th Symposium on Fire and Forest Meteorology, 13-15 November 2001, Reno, Nevada. p. 115.

Gifford, F. A. 1962. Use of routine meteorological observations for estimating atmospheric dispersion. Nuclear Safety. 2(4):47-51.

Holzworth, George C. 1972. Mixing heights, wind speeds and potential for urban air pollution throughout the contiguous united states. Environmental Protection Agency, Office of Air Programs Publication NO. AP-101. Research Triangle Park, NC 27711. 118 p.

Lavdas, L.G. 1986. An Atmospheric Dispersion Index for Prescribed Burning. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. Research Paper SE-256. 35 pp.

Lavdas, L.G. 1997. Estimating Stability Class in the Field. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. Research Note SRS-4.

Pasquill, F. 1961. The estimation of the dispersion of windborne material. Meteorological Magazine. 90:33-49.

Pasquill, F. 1974. Atmospheric Diffusion: The Dispersion of Windborne Material from Industrial and Other Sources. 2nd Edition. John Wiley and Sons, New York. 429 pp.

Schroeder, M.J. and C.C. Buck. 1970. Fire Weather: A guide for application of meteorological information to forest fire control operations. U.S. Department of Agriculture, Forest Service, Agriculture Handbook 360. 229 pp.

Turner, D.B. 1961. Relationship between 24-hr. Mean air quality measurement and meteorological factors in Nashville, TN. Journal of Air Pollution Control Association. 11:483-489.

Turner, D.B. 1964. A diffusion model for an urban area. Journal of Applied Meteorology. 3:83-91.

Turner, D.B. 1970. Workbook of Atmospheric Dispersion Estimates. Office of Air Programs Pub. No. AP-26, U.S. Environmental Protection Agency, Research Triangle Park, NC.

Chapter 8

SMOKE MANAGEMENT TECHNIQUES

Smoke Management: Techniques to Reduce or Redistribute Emissions

Roger D. Ottmar

Janice L. Peterson

Bill Leenhouts

John E. Core

Introduction

A land manager's decision to use a specific burning technique is influenced by many considerations, only one of which is a goal to reduce smoke emissions. Other important considerations include ensuring public and firefighter safety, maintaining control of the fire and keeping it within a given perimeter, complying with numerous environmental regulations, minimizing nuisance and hazard smoke, minimizing operational costs, and maximizing the likelihood of achieving the land management objective of the burn. Often these other considerations preclude the use of techniques that 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 activity-generated.

Emission reduction techniques (or best available control measures–BACM) are not without potential negatives and must be prescribed and used with careful professional judgment and full awareness of possible tradeoffs. Fire behavior is directly related to both fire effects and fire emissions. Emission reduction techniques alter fire behavior and fire effects and can impair or prevent accomplishment of land management objectives. In addition, emission reduction techniques do not necessarily reduce smoke impacts and some may, under certain circumstances, actually increase the likelihood that smoke will impact the public. 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; or they may be dangerous or expensive to implement.

Land managers are concerned about the repeated application of any resource treatment technique that does not replicate the ecological role that fire plays in the environment. Such applications may result in unintended resource damage, which may only be known far in the future. Some examples of resource damage that could occur from the use of emission reduction techniques include the loss of nutrients to the soil if too much woody debris is removed from the site, or the effects of soil compaction associated with mechanical processing (chipping, shredding, or yarding) of fuels. The application of herbicides and other chemicals and/or the effects on soils of the intense heat achieved during mass ignition are also of concern. These issues are difficult to quantify but are of universal importance to land managers, who must weigh the impact of their decisions on long-term ecosystem productivity.

Multiple resource values must be weighted along with air quality benefits before emission reduction techniques are prescribed. Flexibility is key to appropriate application of emission reduction techniques and use of particular techniques should be decided on a case-by-case basis. Emission reduction goals may be targeted but the appropriate mix of emission reduction techniques to achieve those goals will require a careful analysis of the short and long term ecological and social costs and benefits. Air quality managers and land managers should work together to better understand the effectiveness, options, difficulties, applicability, and tradeoffs of emission reduction techniques.

There are two general approaches to managing the effects of wildland fire smoke on air quality:

1. *Use techniques that reduce the emissions produced for a given area treated.*
2. *Redistribute the emissions through meteorological scheduling and by sharing the airshed.*

Although each method can be discussed independently, fire practitioners often choose lighting and fuels manipulation techniques that complement, or are consistent with, meteorological scheduling for maximum smoke dispersion and favorable plume transport.

Meteorological scheduling is often the most effective way to prevent direct smoke impacts to the public and some emission reduction techniques may actually increase the likelihood of smoke impacts by decreasing the energy in the plume resulting in more smoke close to the ground. A few of the potential negative consequences of specific emission reduction techniques are mentioned in this chapter although this topic is not addressed comprehensively.

Use of Smoke Management Techniques

Much of the information presented in this chapter was gathered from fire practitioners at three national workshops held during the fall of 1999. Practitioners were asked to describe how (or if) they apply emission reduction techniques in the field, how frequently these methods are used, how effective they are, and what constraints limit their wider use. The information gained at each of the workshops was then synthesized into a draft report that was distributed to the participants for further review and comment. Twenty-nine emission reduction and emission redistribution methods within seven major classifications were identified as currently in use to reduce emissions and impacts from prescribed burning.

The emission reduction methods described in this document may be used independently or in combination with other methods on any given burn. In addition, a number of different firing methods potentially can be applied to any given parcel of land depending on the objectives and judgments made by the fire manager. As a result, no two burns are the same in terms of pollutant emissions, smoke impacts, fuel consumption, or other parameters.

Significant changes in public land management have occurred since EPA's release of the first document describing best available control measures (BACM) for prescribed burning (EPA 1992). Some of these changes have dramatically impacted when and how emission reduction methods for prescribed fire can be applied. On federally managed lands, the following constraints apply to many of the emission reduction techniques: National Environmental Policy Act (NEPA), Threatened and Endangered Species (T&E) considerations, water quality and impacts on riparian areas, administrative constraints imposed by Congress (eg, roadless and wilderness area designations), impacts on archaeological resources, smoke management program requirements, and other state environmental or forestry regulations.

The following emission reduction and emission redistribution techniques are a comprehensive compilation of the current state of the knowledge. Any one of these 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.

Reducing the Amount of Emissions

Emissions from wildland fire are complex and contain many pollutants and toxic compounds. Emission factors for over 25 compounds have been identified and described in the literature (Ward and Hardy 1991; Ward and others 1993). A simplifying finding from this research is that all pollutants except nitrous oxide (NO_x) are negatively correlated with combustion efficiency, so actions that reduce one pollutant results in the reduction of all (expect NOx). Nitrous oxide and CO_2 (not considered a pollutant) can increase if the emission reduction technique increases combustion efficiency.

Emission reduction techniques may reduce emissions from a given prescribed burn area by as much as about 60 percent to as little as virtually zero[1]. Considering all burning nationally, if emission reduction techniques were optimally used, emissions could probably be reduced by approximately 20-25 percent assuming all other factors (vegetation types, acres, etc.) were held constant and land management goals were still met[1]. Individual states or regions may be able to achieve greater emission reductions than this or much less depending on the state's or region's biological decomposition capability or ability to utilize available biomass.

In the context of air quality regulatory programs, current or future emissions are typically measured against those that occurred during a baseline period (annual, 24-hour, and seasonal) to determine if reductions have or will occur in the future. Within this framework, land managers need to know their baseline emissions to determine the degree of emission reduction that a method described here will provide in order to conform to a State Implementation Plan, State Smoke Management Program, or local nuisance standards.

Because of all these variables, wildland fire emission models such as the First Order Fire Effects Model (FOFEM) (Reinhardt and others 1997), Consume 2.1 (Ottmar and others [in

[1] Peterson, J. and B. Leenhouts. 1997. What wildland fire conditions minimize emissions and hazardous air pollutants and can land management goals still be met? An unpublished technical support document to the EPA Interim Air Quality Policy on Wildland and Prescribed Fires. August 15, 1997. (Available from the authors or online at http://www.epa.gov/ttncaaa1/faca/pbdirs/emissi.pdf

preparation]), and Emissions Production Model (EPM) (Sandberg and Peterson 1984) can be used to estimate particulate, gaseous and hazardous pollutant emissions based on the specifics of each burn. There are seven general categories that encompass all of the techniques described in this document. Each is described below.

1. Reduce the Area Burned

Perhaps the most obvious method to reduce wildland fire emissions is to reduce the area burned. Area burned can be reduced by not burning at all or by burning a subset of the area within a designated perimeter. Caution must be applied though, and programs to reduce the area burned must not ultimately result in just a delay in the release of emissions either through prescribed burning at a later date or as the result of a wildland fire. 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.

This technique can have detrimental effects on ecosystem function in fire-adapted vegetation community types and is least applicable when fire is needed for ecosystem or habitat management, or forest health enhancement. In some areas and some vegetation types, when fire is used to eliminate an undesirable species or dispose of biomass waste, alternative methods can be used to accomplish effects similar to what burning would accomplish. Examples of specific techniques include:

- **Burn Concentrations.** Sometimes concentrations of fuels can be burned rather than using fire on 100 percent of an area requiring treatment. The fuel loading of the areas burned using this technique tend to be high. The total area burned under these circumstances can be very difficult to quantify.

- **Isolate fuels.** Large logs, snags, deep pockets of duff, sawdust piles, squirrel middens, or other fuel concentrations 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 allows targeted fuels to remain following the prescribed burn.

- **Mosaic burning**. Landscapes often contain a variety of fuel types that are non-continuous and vary in fuel moisture content. Prescribed fire prescriptions and lighting patterns can be assigned to use this fuel and fuel moisture non-homogeneity to mimic a natural wildfire 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. For example, an area may be continuously ignited during a prescribed fire but because the fuels are not continuous, patches within the unit perimeter may not ignite and burn (figure 8.1). Depressional wetlands, swamps, and hardwood stringers can be excluded by burning when soil moisture is abundant. Furthermore, if the burn prescription calls for low humidity and high live fuel moisture, continuous burning in the dead fuels may occur while the live fuels exceed the moisture of extinction. In both cases, the unburned live fuels may be available for future burning in a prescribed or wildland fire during droughts or dormant seasons.

2. Reduce Fuel Load.

Some or all of the fuel can be permanently removed from the site, biologically decomposed, and/or prevented from being produced. Overall emissions can be reduced when fuel is permanently excluded from burning.

- **Mechanical removal**. Mechanically removing fuels from a site reduces emissions proportionally to the amount of fuel removed. This is a broad category and can include such techniques as mechanical removal of logging debris from clearcuts, onsite chipping of woody material and/or brush for offsite utilization, and mechanical removal of fuels which may or may not be followed by offsite burning in a more controlled environment. Sometimes mechanical treatments (such as whole-tree harvesting or yarding of unmerchantable material [YUM]) may result in sufficient treatment so that burning is not needed. Mechanical treatments are applicable on lands where this activity is allowable (i.e., non-wilderness, etc.), supported by an access road network, and where there is an economic market for disposal of the removed fuel. This technique is most effective in forest fuel types and has some limited applicability in shrub and grass fuel types. A portion of the emission reduction gains from this technique may be offset by increased fossil fuel and particulate emissions from equipment used for harvest, transportation, and disposal operations. Mechanical treatments may cause undue soil disturbance or compaction, stimulate alien plant invasion, remove natural nutrient sources, or impair water quality.

- **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 (figure 8.2). If the biomass is spread across the ground as additional litter fuels, emission reductions are not achieved if the litter is consumed either in a prescribed or wildland fire. Use of this technique may eliminate the need to burn.

- **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 access. This technique is generally applicable in forest types with large diameter, woody biomass. The emissions from wildland fuels when burned for residential heating are not assessed as wildland fire emissions but as residential heating emissions. The impact of these emissions on the human environment is not attributed to wildland fire in the national or state emissions inventories.

- **Biomass for electrical generation**. Woody biomass can also be removed and used to provide electricity in regions with cogeneration facilities. Combustion efficiency in electricity production is greater than open burning and emissions from biomass fuel used offset fossil fuel emissions. Although this method of reducing fuel loading is cost-effective where there is a market for wood chips, there are significant administrative, logistical, and legal barriers that limit its use.

- **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

Figure 8.1. Mosaic burning creates patches of burned and unburned areas resulting in reduced emissions.

Figure 8.2. Mechanical processing of biomass.

place and year to year. Biomass utilization is most applicable in forest and shrub types that include large diameter woody biomass and where fuel density and accessibility makes biomass utilization economically viable.

- **Ungulates**. Grazing and browsing live grassy or brushy fuels by sheep, cattle, or goats can reduce fuels prior to burning or reduce the burn frequency. Goats will sometimes consume even small, dead woody biomass. However, ungulates are selective, favoring some plants over others. The cumulative effect of this selectivity can significantly change plant species composition and long-term ecological processes on an area, eventually converting grass dominated areas to brush. On moderate to steep slopes, high populations of ungulates contribute to increased soil erosion.

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.

- **Chemical treatments**. Broad spectrum and selective herbicides can be used to reduce or remove live vegetation, or alter species diversity respectively. This often reduces or eliminates the need to use fire. Chemical production and application have their own emissions, environmental, and public relations problems. A NEPA (National Environmental Policy Act) analysis is generally required prior to any chemical use on public lands and states often require similar analyses prior to chemical use on state or private lands.

- **Site conversion**. Natural site productivity can be decreased by changing the vegetation composition. For example, frequent ground fires in southern pine forests will convert an understory of flammable shrubs (such as palmetto and gallberry) to open woodlands with less total fuel but also with more grass and herbs. Grass and herbs tend to burn cleaner than shrubs. Total fuel loading can also be reduced through conversion to species that are less productive.

- **Land use change**. Changing wildlands to another land use category may result in elimination of the need to burn. Conversion of a wildland site to agriculture or an urbanized use significantly alters the ecological structure and function and presents numerous legal and philisophical issues. This alternative is probably not an option on Federally managed lands.

4. Reduce Fuel Consumed.

Emission reductions can be achieved when significant amounts of fuel are at or above the moisture of extinction, and therefore unavailable for combustion. Burning when fuels are wet may leave significant amounts of fuel in the treated area only to be burned in the future. This may not result in a real reduction in emissions then, but rather a delay of emissions to a later date. Real emission reductions are achieved only if the fuels left behind will biologically decompose or be otherwise sequestered at a time of subsequent burning. Even though wet fuels burn less efficiently and produce greater emissions relative to the amount of fuel consumed, emissions from a given event are significantly reduced because so much less fuel is consumed.

In the appropriate fuel types, the ability to target and burn only the fuels necessary to meet management objectives is one of the most effective methods of reducing emissions. When the objective of burning is to reduce wildfire hazard, removal of fine and intermediate diameter fuels may be sufficient. The opportunity to limit large fuel and organic layer consumption can significantly reduce emissions.

- **High moisture in large woody fuels**. Burning when large-diameter woody fuels (3+ inches in diameter or greater) are wet can result in lower fuel consumption and less smoldering. When large fuels are wet they will not sustain combustion on their own and are extinguished by their own internal moisture once the small twigs and branch-wood in the area finish burning (figure 8.3). The large logs therefore consume less in total, they do not smolder as much, and they do not cause as much of the organic layer on the forest floor to burn. This can be a very effective technique for reducing total emissions from a prescribed burn area and can have secondary benefits by leaving more large-woody debris in place for nutrient cycling. This technique can be effective in natural and activity fuels in forest types. When large fuel consumption is needed, burning under high moisture conditions is not a viable alternative.

Figure 8.3. Burning when large fuel moisture is high can result in less total fuel consumption.

- **Moist litter and/or duff**. The organic layer that forms from decayed and partially decayed material on the forest floor often burns during the inefficient smoldering phase. Consequently, reducing the consumption of this material can be very effective at reducing emissions. Consumption of this litter and/or duff layer can be greatly reduced if the material is quite moist. The surface fuels can be burned and the organic layer left virtually intact. The appropriate conditions for use of this technique generally occurs within a few days of a soaking rain or shortly after snowmelt. This technique is most effective in non-fire adapted forest and brush types. This technique may not be appropriate in areas where removal of the organic layer is desired. Burning litter and/or duff to expose mineral soil is often necessary in fire adapted ecosystems for plant regeneration.

- **Burn before precipitation.** Scheduling a prescribed fire before a 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 reducing the fire average emission factor. Sucessful application of this procedure depends on accurate meteorological forecasts for the area.

- **Burn before large fuels cure**. Living trees contain very high internal fuel moistures, which take a number of months to dry after harvest. If an area can be burned within 3-4 drying months of timber harvest, many of the large fuels will still contain a significant amount of live fuel moisture. This technique is generally restricted to activity-generated fuels in forest-types.

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.

- **Burn before litter fall**. When decidous trees and shrubs drop their leaves this ground litter contributes extra volume to the fuel bed. If burning takes place prior to litter fall there is less available fuel and therefore less fuel consumed and fewer emissions.

- **Burn before green-up**. Burning in cover types with a grass and/or herbaceous fuelbed 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.

6. Increase Combustion Efficiency.

Increasing combustion efficiency, or shifting the majority of consumption away from the smoldering phase and into the more efficient flaming phase, reduces emissions.

- **Burn piles or windrows**. Fuels concentrated into clean and dry piles or windrows generate greater heat and burn more efficiently (figure 8.4). A greater amount of the consumption occurs in the flaming phase and the emission factor is lower. This technique is primarily effective in forest fuel types but may have some applicability in brush types also. 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 smoke problems.

- **Backing fires**. Flaming combustion is cleaner than smoldering combustion. A backing fire takes advantage of this relationship by causing more fuel consumption to take place in the flaming phase than

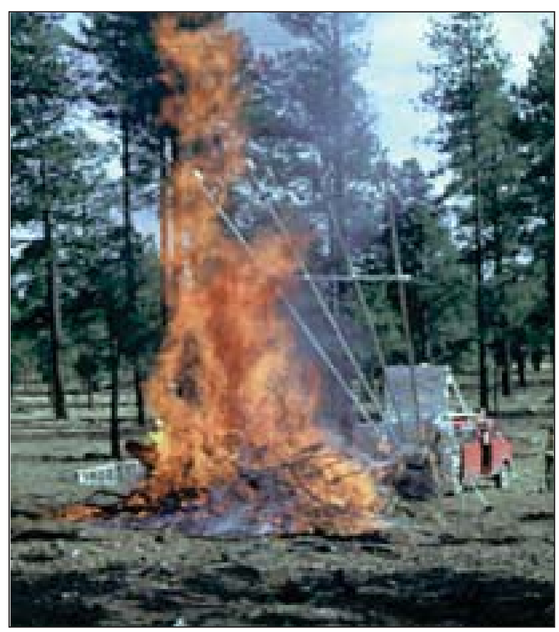


Figure 8.4. Fuels burned in dry, clean piles burn more efficiently and generate less emissions

would occur if a heading fire were used (figure 8.5). In applicable vegetation types where fuels are continuous and dry, the flaming front backs more slowly through the fuelbed and by the time it passes, most available fuel is consumed so the fire quickly dies out with very little smoldering. In a heading fire, the flaming front passes quickly and the ignited fuels continue to smolder until consumed. The opportunity to use backing fires is not always an option and often increase operational costs.

- **Dry conditions**. Burning under dry conditions increases combustion efficiency and less emissions may be produced. However, dryer conditions makes fuel that was not available to burn (at or above the moisture of extinction) available to burn. The emissions from additional fuel burned generally more than offsets emission reduction advantages gained by greater combustion efficiency. This technique is effective only if all fuels will consume under either wet or dry conditions.

Figure 8.5. Backing fires in uniform, noncomplex fuelbeds consume fuels more efficiently than during a head fire resulting in fewer emissions.

- **Rapid mop-up**. Rapidly extinguishing a fire can reduce fuel consumption and smoldering emissions somewhat although this technique is not particularly effective at reducing total emissions and can be very costly (figure 8.6). Rapid mop-up primarily effects smoldering consumption of large-woody fuels, stumps, snags, and duff. 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.

- **Aerial ignition / mass ignition**. “Mass” ignition can occur through a combination of dry fine-fuels and very rapid ignition, which can be achieved through a technique such as a helitorch (figure 8.7). 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 convec-

Figure 8.6. Quickly extinguishing a smoldering fire is a costly but effective technique for reducing smoldering emissions and impacts.

Figure 8.7. Mass ignition can shorten the duration of the smoldering phase and reduce total consumption resulting in fewer emissions

tion column which draws much of the heat away from the fuelbed and prevents drying and preheating of larger, moister fuels. This strong plume may result in improved smoke dispersal. The fire dies out shortly after the fine fuels fully consume and there is little smoldering or consumption of the larger fuels and duff. The conditions necessary to create a true mass ignition situation include rapid ignition of a large, open area with continuous, dry fuels (Hall 1991).

- **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 (figure 8.8). These devices are commonly used to burn land clearing, highway right-of-ways, or demolition debris in areas sensitive to smoke and may be required by air quality agency regulations in some areas.

Redistributing the 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. Redistribution of emissions does not necessarily reduce overall emissions.

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.

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.

Figure 8.8. Air curtain incinerators result in very hot and efficient fires that produce little smoke.

3. Avoid sensitive areas.

The most obvious way to avoid smoke impacts is to burn when the wind is blowing away from all smoke-sensitive areas such as highways, airports, populated areas, and scenic vistas. Wind direction must be considered during all phases of burning. For example, the prevailing winds during the day time may move the smoke away from a major highway; however, at night, drainage winds can carry the smoke toward the highway.

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.

5. Burn more frequently.

Burning more frequently does not allow fuels to accumulate, thus there are less emissions with each burn. Frequent, low intensity fires can prevent unwanted vegetation from becoming established. If longer fire rotations are used, the vegetation has time to grow resulting in the production of extra biomass and extra fuel loading at the time of burning. This technique generally has positive effects on land management goals since it results in fire regimes that more closely mimic the frequency of natural fire in many ecosystems.

The Use and Effectiveness of Emission Reduction and Redistribution Techniques

The overall potential for emission reductions from prescribed fire depends on the frequency of use of emission reduction techniques and the amount of emission reduction that each method offers. This section provides information on the overall potential for emission reduction and redistribution from prescribed fire based on (a) the frequency of use of each emission reduction and emission redistribution technique by region of the country, (b) the relative effectiveness of each smoke management technique, and (c) constraints on application of the technique (administrative, legal, physical, etc.).

Much of the information in this section was provided by participants in regional workshops (as described previously). The information provided can, and should, be improved upon by local managers who will have better information about specific, local burning situations.

The use of each smoke management technique is organized by U.S. region as shown in figure 8.9. They are the Pacific Northwest including Alaska (PNW), Interior West (INT), Southwest (SW), Northeast (NE), Midwest (MW), and Southeast including Hawaii (SE) regions. Each region has its own vegetation cover types, climatology, and terrain characteristics, all of which influence the land manager's decision to burn and the appropriateness of various emission reduction techniques.

Manager use of emission reduction techniques is influenced by numerous factors including land management objectives, the type and amount of vegetation being burned, safety considerations, costs, laws and regulations, geography, etc. The effect of some of these many influencing factors can be assessed through general knowledge of the frequency of use of a particular technique in a specific region. Table 8.1 provides general information about frequency of use of each smoke management technique by region of the country, grouped as shown in figure 8.9.

Figure 8.9. Prescribed burning regions including Pacific Northwest including Alaska (PNW), Intermountain (INT), Midwest (MW), Southwest (SW), Southeast including Hawaii (SE), and Northeast (NE).

Information in table 8.1 summarizes regional applicability of each of the twenty-nine smoke management methods. Interviews with fire practitioners demonstrate that, on a national scale, several smoke management techniques are rarely used. These include biomass for electrical generation, biomass utilization, site conversion, land use change, burning before litter fall, burning under dry conditions, air curtain incineration, and burning smaller units. In most of the regions, firewood sales and chemical treatments are also seldom used. The methods most commonly applied include aerial ignition/mass ignition, burning when dispersion is good, sharing the airshed, and avoiding sensitive areas.

The general effectiveness of the emission reduction and redistribution techniques is described in table 8.2 based on input from managers at the workshops. Local managers will have better information about specific situations and can improve upon the information in the tables. 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

Table 8.1. Frequency of smoke management method use by region. Alaska is included in the Pacific Northwest (PNW) region, and Hawaii is included in the southeast region (SE)

Smoke Management Method	Frequency of Use by Region		
	Rarely	Occasionally	Commonly
1. Reduce the Area Burned			
• Burn Concentrations	SE	NE, MW, SW, PNW	INT
• Isolate Fuels		NE, SE, MW, SW	INT, PNW
• Mosaic Burning	NE, SE, MW		INT, SW, PNW
2. Reduce Fuel Load			
• Mechanical Removal	NE, MW	SE	INT, SW, PNW
• Mechanical Processing	SW	NE, SE, MW, INT, PNW	
• Firewood Sales	NE, SE, MW, INT, PNW	SW	
• Biomass for Electrical Generation	All Regions		
• Biomass Utilization	All Regions		
• Ungulates		NE, SE, MW	INT, SW, PNW
3. Reduce Fuel Production			
• Chemical Treatment	NE, MW, INT, SW, PNW	SE	
• Site Conversion	All Regions		
• Land Use Change	All Regions		
4. Reduce Fuel Consumed			
• High Moisture in Large Fuels		NE, MW, INT, SW	SE, PNW
• Moist Litter &/or Duff	SW	NE, MW, INT	SE, PNW
• Burn Before Precipitation		All Regions	
• Burn Before Large Fuels Cure	SE, INT, SW		NE, MW, PNW
5. Schedule Burning Before New Fuels Appear			
• Burn Before Litter Fall	All Regions		
• Burn Before Green Up		INT, PNW	NE, SE, MW, SW
6. Increase Combustion Efficiency			
• Burn Piles or Windrows	SE	NE, MW	INT, SW, PNW
• Backing Fires	INT	PNW	NE, SE, MW, SW
• Dry Conditions	All Regions		
• Rapid Mop-up		SE, INT, SW	NE, MW, PNW
• Aerial Ignition/Mass Ignition			All Regions
• Air Curtain Incinerators	All Regions		
7. Redistribute Emissions			
• Burn when dispersion is good			All Regions
• Share the airshed			All Regions
• Avoid sensitive areas			All Regions
• Burn smaller units	All Regions		
• Burn more frequently	NE, MW, SW, PNW	INT	SE

Table 8.2. Relative effectiveness of various smoke management techniques.

Smoke Management Technique	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		✓

smoldering combustion where smoke is more likely to get caught in drainage winds and carried into populated areas. These factors are also addressed in table 8.2.

Table 8.3 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 specific constraints could be overcome.

Smoke management techniques that, in the opinion of workshop participants, show particular promise for wider use in the future are listed below:

1. **Mosaic Burning:** Since this method reduces the area burned and replicates the natural role of fire, it is being increasingly used for forest health restoration burning on a landscape scale.

2. **Mechanical Removal:** In areas where slope and access are not a problem and fuels have economic value, the wider use of whole tree yarding, YUM yarding, cut-to-length logging practices and other methods that remove fuel from the unit prior to burning (if the unit is burned at all) may have potential for wider application if economic markets for the removed fuels can be found.

3. **High Moisture in Large Woody Fuels, and/or Moist Litter and Duff:** In situations where the objective is not to maximize the consumption of large woody debris, litter, and/or duff, this option is favored by fire practitioners as an effective means of reducing emissions, smoldering combustion, and smoke impacts.

4. **Pile and Windrow Burning:** Pile burning, although already widely used in all regions, is gaining popularity among land managers because of the flexibility offered in scheduling burning and the resultant lower impacts on smoke sensitive locations. Lower impacts may not result if piles or windrows are wet or mixed with dirt.

5. **Aerial/Mass Ignition**: Little clear information currently exists as to the extent to which aerial ignition achieves true mass ignition and associated emission reduction benefits. More effort to achieve true mass ignition using aerial techniques may yield significant emission reduction benefits.

6. **Burn More Frequently:** Fire managers generally favor more frequent burning practices to reduce fuel loading on second and subsequent entry, thereby reducing emissions over long time periods. This will increase daily or seasonal emissions.

Estimated Emission Reductions

While the qualitative assessment of emission reduction technique effectiveness shown in table 8.2 is a useful way to gauge how relatively successful a particular technique may be in reducing emissions, it is also useful to model potential quantitative emission reduction. Table 8.4 summarizes potential emission reductions that may be achieved by employing various techniques as estimated by the fuel consumption and emissions model Consume 2.1 (Ottmar and others [in preparation]). For example, use of mosaic burning techniques in natural, mixed conifer fuels in which one-half of a 200-acre project is burned is projected to reduce $PM_{2.5}$ emissions from 14.8 to 7.4 tons for a 50% reduction in emissions. A 33% reduction in

Table 8.3. Constraints to the use of emission reduction and redistribution techniques as reported by regional workshop participants.

Smoke Management Method	Constraints				
	Administrative	Physical	Legal	Cost	Other
1. Reduce the Area Burned					
• Burn Concentrations	Few	Slope and 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 and Access	Few	High	Incompatible fuels
• Firewood Sales	High	Access	High	Few	No markets, incompatible fuels
• Biomass for Electrical Generation	High	Slope and Access	Moderate	High	No markets, incompatible fuels
• Biomass Utilization	High	Slope and 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 and Duff	Few	Few	Few	Few	Not used in the 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
6. Increase Combustion Efficiency					
• Burn Piles and Windrows	Few	Slope	Few	High	
• Backing Fires	Few	Fuel continuity	Few	Few	Need correct meteorological conditions
• Dry Conditions	High	Dry conditions	High	High	Increased escape potential
• Rapid Mop-Up	Few	Slope and access	Few	High	
• Aerial Ignition/Mass Ignition	Few	Few	Few	Moderate	Trained crews and equipment; fuel types
• Air Curtain Incinerators	Few	Access	Few	Very high	
7. Redistribute Emissions					
• Burn When Dispersion is Good	Few	Moderate	Few	Moderate	Increased escape potential
• 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	Smoke management windows and cost

Table 8.4. Approximate emission reduction effectiveness for various emission reduction techniques in certain vegetation types. (Values generated with Consume 2.1 [Ottmar and others, in preparation]).

Emission Reduction Technique	Vegetation Type	Total Fuel Loading (tons/acre)	Fuel Type[1]	Size (acres)	Ignition Time[2] (minutes)	Large Fuel Moisture[3] (percent)	Duff Moisture[4] (percent)	Total Fuel Consumption (tons)	Total PM_{10} Emissions (tons)	PM10 Emission Reduction (percent)	Total $PM_{2.5}$ Emissions (tons)	$PM_{2.5}$ Emission Reduction (percent)
Mosaic Burning	Southern pine	10.9	Natural	100	180	N/A	120	296	3.09	50	2.95	50
Non-mosaic Burning	Southern pine	10.9	Natural	200	180	N/A	120	593	6.19		5.91	
Mechanical removal	North central red and white pine	19.4	Activity	100	180	30	N/A	1,659	15.65	40	14.82	42
No Mechanical removal	North central red and white pine	32.4	Activity	100	180	30	N/A	2,531	26.42		25.56	
Ungulates	Midwest grassland	1.0	Natural	100	N/A	N/A	120	17	0.17	70	0.06	67
No Ungulates	Midwest grassland	1.4	Natural	100	N/A	N/A	120	57	0.57		0.18	
High Moisture in Large Fuels	Interior mixed conifer	96.9	Activity	100	180	40	N/A	3,924	34.92	44	32.65	43
Low Moisture in Large Fuels	Interior mixed conifer	96.9	Activity	100	180	15	N/A	7,270	62.33		57.67	
Moist Litter and/or Duff	Alaska black spruce	30.8	Natural	100	N/A	N/A	120	1,492	13.19	26	12.39	26
Dry Litter and/or Duff	Alaska black spruce	30.8	Natural	100	N/A	N/A	40	1,909	17.83		16.85	
Burn Before Large Fuels Cure	Pacific Northwest Douglas-fir/hemlock	118.6	Activity	100	180	100	N/A	3,165	24.82	45	22.47	44
Burn After Large Fuels Cure	Pacific Northwest Douglas-fir/hemlock	118.6	Activity	100	180	30	N/A	6,194	45.21		40.10	
Piled Fuels	Southwest Ponderosa pine	43.2	Piled	100	N/A	N/A	N/A	8,549	31.16	9	27.14	13
Non-piled Fuels	Southwest Ponderosa pine	44.6	Activity	100	180	30	N/A	2,672	34.16		31.34	
Mass Ignition	Pacific Northwest Douglas-fir/hemlock	118.6	Activity	100	30	40	N/A	5,597	40.77	10	36.13	10
No Mass Ignition	Pacific Northwest Douglas-fir/hemlock	118.6	Activity	100	180	40	N/A	6,195	45.21		40.10	
Burn More Frequently	California chaparral	6.7	Natural	100	N/A	N/A	120	469	3.87	83	3.17	83
Burn Less Frequently	California chaparral	39.7	Natural	100	N/A	N/A	120	2,779	22.93		18.76	

[1] Activity fuels are woody debris resulting from management activity such as logging.
[2] A tractor piled unit does not require ignition time for Consume 2.1.
[3] A natural fuel unit or piled unit does not require large woody fuel moisture content input for Consume 2.1.
[4] An activity fuel units or piled unit does not require duff moisture content input for Consume 2.1

$PM_{2.5}$ emissions can be achieved by pile burning mixed conifer fuels under the conditions noted in the table. Specific simplifying assumptions were made in each case to produce the estimates of emission reduction potential seen in table 8.4. Other models using the same field assumptions would yield similar trends.

Wildfire Emission Reduction

Little thought has been given to reducing emissions from wildfire, but many fire management actions do affect emission production from wildfires because they intentionally reduce wildfire occurrence, extent, or severity. For example, fire prevention efforts, aggressive suppression actions, and fuel treatments (mechanical or prescribed fire) all reduce emissions from wildfires. Although fire suppression efforts may only delay the emissions rather then eliminate them altogether. Allowing fires to burn without suppression early in the fire season to prevent more severe fires in drier periods would reduce fuel consumption and reduce emissions. All fire management plans that allow limited suppression consider air quality impacts from potential wildfires as a decision criterion. So, although only specific emission reduction techniques for prescribed fires are discussed in this chapter, we should remember that there is an inextricable link between fuels management, prescribed fire, wildfire severity, and emission production.

Literature Citations

Environmental Protection Agency. Sept. 1992. Prescribed burning background document and technical information document for prescribed burning best available control methods. U.S. EPA, Office of Air Quality Planning and Standards. Research Triangle Park, NC. EPA-450/2-92-003.

Hall, Janet. 1991. Comparison of fuel consumption between high and moderate intensity fires in logging slash. Northwest Science. 64(4): 158-165.

Ottmar, Roger D.; Reinhardt, Timothy E.; Anderson, Gary, DeHerrera, Paul J. [In preparation]. Consume 2.1 User's guide. Gen. Tech. Rep. PNW-GTRxxx. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.

Reinhardt, Elizabeth D.; Keane, Robert E.; Brown, James K. 1997. First Order Fire Effects Model: FOFEM 4.0, users guide. Gen. Tech. Rep. INT-GTR-344. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 65 p.

Sandberg, D.V.; Peterson, J. 1984. A source strength model for prescribed fires in coniferous logging slash. Presented at the 1984 Annual Meeting, Air Pollution Control Association, Pacific Northwest Section, 1984 November 12.

Ward, Darold E.; Hardy, Colin C. 1991. Smoke emissions from wildland fires. Environmental International, Vol 17:117-134.

Ward, Darold E.; Peterson, Janice; Hao, Wei Min. 1993. An Inventory of Particulate Matter and Air Toxic Emissions from Prescribed Fires in the USA for 1989. In: Proceedings of the 86th Annual Meeting of the Air and Waste Management Association; 1993 June 13-18; Denver, CO. 19p.

Chapter 9

DISPERSION PREDICTION SYSTEMS

Smoke Dispersion Prediction Systems

Sue A. Ferguson

Smoke dispersion prediction systems are becoming increasingly valuable tools in smoke management. There are a variety of potential applications that can help current management issues. These include screening, where methods and models are used to develop "worst-case" scenarios that help determine if alternative burn plans are warranted or if more in-depth modeling is required. Such tools also help in planning, where dispersion predictions aid in visualizing what fuel and weather conditions are best suited for burning or when supporting data are needed to report potential environmental impacts. Also, prediction systems can be used as communication aids to help describe potential impacts to clients and managers. For regulating, some states use dispersion prediction systems to help determine approval of burn permits, especially if ignition patterns or fuel complexes are unusual. Other states require dispersion model output in each burn permit application as supporting proof that a burn activity will not violate clean air thresholds.

There are a variety of tools that can be applied to screening and some planning applications. The easiest of these are simple approximations of dispersion potential, emission production, and proximity to sensitive receptors. The approximations are based on common experience with threshold criteria that consider worst-case conditions or regulatory requirements. More detailed planning and many regulatory situations require numerical modeling techniques. While numerical models output a calculated physical approximation of dispersion features, they can be adjusted to predict worst-case scenarios by altering such things as emission production or trajectory winds. Often the easily applied numerical models are used for screening. Typically, more rigorous applications require the use of complex models by trained personnel.

Methods of Approximation

A first level of approximation can simply determine whether the atmosphere has the capacity to effectively disperse smoke by using indexes of ventilation or dispersion. These indexes are becoming widely used and may be a regular feature of fire weather or air quality forecasts in your area. Usually the ventilation index is a product of the mixing height times the average wind within the mixed layer. For example, a mixing height of 600 meters (~2,000 feet) above the ground surface with average winds of 4 m/s (~7.8 knots or ~8.9 mph) produces a ventilation index of 2,400 m^2/sec (~15,600 knots-feet). With similar wind speeds, the ventilation index would increase to 12,000 m^2/sec (~78,000 knots-feet) if the mixing height rose to 3,000 meters (~10,000 feet). Ventilation indexes calculated from model output may use the product of the planetary boundary layer (PBL) and lowest level winds (e.g., 10 to 40 meters above ground level). Others calculate the index by multiplying the mixing height by a determined transport wind speed,[1] which might be near the top of the mixed layer. Because of different methods of calculating ventilation index, the scales used for burning recommendations may vary.

It helps to gain experience with a ventilation index before making management decisions based on its value. Defining a uniform method for calculating the index and comparing it frequently with observed smoke dispersal conditions can do this. Ferguson et al. (2001) developed a national historical database of ventilation index based on model generated 10-meter winds and interpolated mixing height observations. It is useful in illustrating the spatial and temporal variability of potential ventilation all across the country. In South Carolina the index is divided into 5 categories that correspond to specific prescribed burning recommendations, where no burning is recommended if the index is less than 4,500 m^2/sec (28,999 knots-feet) and restrictions apply if it is between 4,500 and 7,000 m^2/sec (29,000-49,999 knots-feet) (South Carolina Forestry Commission, 1996). In Utah the ventilation index is referred to as a "clearing index" and is defined as the mixing depth in feet times the average wind in knots divided by 100. In this way, a clearing index of less than 200 would indicate poor dispersion and likely pollution; an index between 200 and 500 indicates fair dispersion, while indexes greater than 500 represent good to excellent dispersion. Commonly, the clearing index must be greater than 400 before burning is recommended. In the northwestern U.S., where a mesoscale weather model is used to predict ventilation index, the South Carolina scale has been slightly adjusted to match local burning habits and to accommodate for the slightly different way of computing the index. Table 9.1 gives common values of the ventilation index (VI) and associated smoke conditions.

Ventilation indexes have no value when there is no mixing height, which is common at night. Also, if the atmosphere is very stable within the mixed layer, the ventilation index may be too optimistic about the ultimate potential of dispersing a smoke plume. Therefore, to help

Table 9.1. Common values of the ventilation index (VI) and associated smoke conditions. The Index is calculated by multiplying mixing height (MH) or planetary boundary layer (PBL) times trajectory winds (Traj.), average winds through the depth of the mixed layer (Avg.), or winds at 40 meters above ground level (40m).

VI (knots-ft) MH x Traj.	**VI (knots-ft)/100 MH x Avg.**	**VI (m^2/sec) PBL x 40m**	**Smoke Condition**
0-28,999	< 200	< 2,350	Poor
29,000-37,999	200-400	2,350-4,700	Marginal
38,000-49,999	400-500	4,700-7,050	Fair
50,000-94,999	>500	>7,050	Good
> 95,000			Excellent dispersion - but burn with caution

[1] Transport winds are those considered most likely to carry smoke away from a fire, usually near mid-level of the horizontal portion of a spreading plume.

determine the atmosphere's capacity to disperse smoke during all atmospheric conditions, Lavdas (1986) developed an Atmospheric Dispersion Index (ADI) that combines Pasquill's stability classes (see table 7.1) and ventilation indexes with a simple dispersion model. National Weather Service (NWS) fire weather offices are beginning to include the ADI as a regular part of their smoke management forecast. See table 9.2 for an explanation of the ADI categories. Commonly the ADI must be greater than 30 before burning is recommended.

Another way to approximate smoke impacts is through a geometric screening process that is outlined in "A Guide for Prescribed Fire in Southern Forests" (Wade 1989) and "Southern Forestry Smoke Management Guidebook" (USDA-Forest Service, Southern Forest Experiment Station 1976). The recommended steps include: 1) plotting the direction of the smoke plume, 2) identifying common areas of smoke sensitivity (receptors) such as airports, highways, hospitals, wildernesses, schools, and residential areas, 3) identifying critical areas that already have an air pollution or visibility problem (non-attainment areas), 4) estimating smoke production, and 5) minimizing risk.

It is suggested that the direction of the smoke plume during the day be estimated by considering the size of the fire and assuming a dispersion of 30° on either side of the centerline trajectory if wind direction is planned or measured and 45° if forecasted winds are used. At night, the guide suggests that smoke follows down-valley winds and spreads out to cover valley bottoms. Fuel type, condition, and loading are used to help estimate the amount of smoke that will be produced. In minimizing risk, it is suggested to consider mixing height, transport wind speed, background visibility, dispersion index, and various methods of altering ignition and mop-up patterns.

Because the guidebooks for southern forestry estimate emissions based on fuel types specific to the southeastern U.S., other methods of

Table 9.2. Atmospheric Dispersion Index (ADI) with its current interpretation (Lavdas 1986).

ADI	Interpretation
1-6	Very poor dispersion (common during nighttime)
7-12	Poor dispersion
13-20	Generally poor dispersion
21-40	Fair dispersion (but stagnation may occur if wind speeds are low)
41-60	Generally good dispersion (common in afternoon of U.S. interior)
61-100	Good dispersion (commonly related to good burning weather)
> 100	Very good dispersion (but may relate to high fire hazard)

estimating emissions are needed to employ geometric screening applications elsewhere. Existing models such as FOFEM (Reinhardt and others 1997) and CONSUME (Ottmar and others 1993) are designed for this purpose.

Schaaf and others (1999) describe a similar screening process for deciding the level of analysis for each project. The screening steps include: 1) determining fire size, 2) estimating fuel load, 3) identifying distance to sensitive areas, and 4) calculating emission production. Unlike the southern forestry screening method, which estimates downwind impacts from simple geometry, Schaaf and others (1999) recommend running a numerical dispersion model to help calculate smoke concentrations if initial screening thresholds are met. Further analysis or efforts to reduce potential impacts are then recommended only if predicted concentrations exceed specified standards.

Before relying on simple screening methods to determine if additional modeling may be required or if alternatives are necessary, it is helpful to define appropriate threshold criteria by consulting regulations, surrounding community opinions, and management concerns. For example, the criteria of sensitive receptor proximity may range from fractions of a mile to several miles. On the other hand, some places may base criteria on total tonnage of emissions, no matter how close or far from a sensitive area. Most often criteria are combinations of proximity to receptors and fire size, which vary from place to place.

Numerical Models

Most of the available dispersion prediction systems are in the form of deterministic numerical models and there are three types designed to estimate the timing and location of pollutant concentrations; dispersion, box, and three-dimensional grid models. Dispersion models are used to estimate smoke and gas concentrations along the trajectory of a smoke plume. Box models do not calculate trajectories of particles but assume smoke fills a box, such as a confined basin or valley, and concentrations vary over time as smoke enters and leaves the box. Grid models are like expanded box models in that every grid cell acts as a confined box. Because trajectories are not explicitly computed, box or grid models may include other enhancements, such as complex computations of chemical interactions. Currently, only dispersion and box models have been adapted for wildland smoke management applications. Work is underway to adapt grid models to smoke problems and this will help in estimates of regional haze because grid models can simulate large domains and usually include critical photochemical interactions. The following summary of numerical models currently used by smoke managers is updated from an earlier review by Breyfogle and Ferguson (1996).

Dispersion Models – Dispersion models track trajectories of individual particles or assume a pattern of diffusion to simplify trajectory calculations. Particle models typically are the most accurate way to determine smoke trajectories. They are labor intensive, however, and more often used when minute changes in concentrations are critical, such as when nuclear or toxic components exist, or when flow conditions are well bounded or of limited extent (e.g., PB-Piedmont by Achtemeier 1994, 1999, 2000). Diffusion models commonly assume that concentrations crosswind of the plume disperse in a bell-shape (Gaussian) distribution pattern. Both plume (figure 9.1a) and puff (figure 9.1b) patterns are modeled. The plume method assumes that the smoke travels in a straight line under steady-state conditions (the speed and direction of particles do not change during the period of model simulation). SASEM (Sestak and Riebau 1988), VSMOKE (Lavdas, 1996), and VSMOKE-GIS (Harms and Lavdas 1997) are examples of plume models. Plume models most commonly are applied in regions of flat or gently rolling terrain but can be used whenever a plume is expected to rise above the influence of underlying terrain. The puff method simulates a continuous plume by rapidly generating a series of puffs (e.g., NFSpuff: Harrison 1995; Citpuff: in TSARS+ by Hummel and Rafsnider 1995; and CALPUFF: Scire and others 2000a). Therefore, like particle models, puff models can be used at times when trajectory winds change, such as during changeable weather conditions or in regions where underlying terrain controls smoke trajectory patterns. Because particle trajectory models and Gaussian diffusion models use coordinate systems that essentially follow particles/parcels as they move (Lagrangian coordinates), sometimes they are referred to as Lagrangian dispersion models.

Particle and puff models must have high spatial and temporal resolution weather data to model changing dispersion patterns. This requires at least hourly weather information at spatial resolutions that capture important terrain features (usually less than 1km). For this reason, particle and puff models currently used for smoke management include a weather module that scales observations or input from external meteorological information, to appropriate spatial and temporal resolutions. For example, TSARS+ is designed to link with the meteorological model NUATMOS (Ross and others 1988) while CALPUFF is linked to CALMET (Scire and others 2000b). NFSpuff (Harrison 1995) and PB-Piedmont (Achtemeier 1994, 1999, 2000) contain internal algorithms that are similar to CALMET and NUATMOS. Most weather modules that are attached to particle and puff models solve equations that conserve mass around terrain obstacles and some have additional features that estimate diurnal slope winds and breezes associated with lakes and oceans at very fine scales.

Unlike most particle or puff models, plume models assume that mixing heights and trajectory winds are constant for the duration of the burn. Therefore, they do not require detailed weather inputs and are very useful when meteorological information is scarce. Plume models, however, will not identify changing trajectories or related concentrations if weather conditions fluctuate during a burn period. Also, when smoke extends beyond a distance that is reasonable for steady-state assumptions, which typically is about 50 km (30 miles), plume approximations become invalid. When terrain or water bodies interact with the plume, steady-state assumptions become difficult to justify, no matter how close to the source. Despite the limitation of plume models in complex terrain, they can be useful if plumes are expected to rise above the influence of terrain or if plumes are confined in a straight line that follows a wide valley when dispersion does not extend beyond the valley walls.

Box and Grid Models – The box method of estimating smoke concentrations assumes instantaneous mixing within a confined area, such as a confined basin or valley (figure 9.1c). This type of model usually is restricted to weather conditions that include low wind speeds and a strong temperature inversion that confines the mixing height to within valley walls (e.g., Sestak and others, unpublished; Lavdas 1982). The valley walls, valley bottom, and top of the inversion layer define the box edges. The end segments of each box typically coincide with terrain features of the valley, like a turn or sudden elevation change. Flow is assumed to be down-valley and smoke is assumed to instantaneously fill each box segment. The coordinates used to calculate box dispersions are fixed in space and time and thus called Eulerian coordinates. The box method provides a useful alternative to Gaussian diffu-

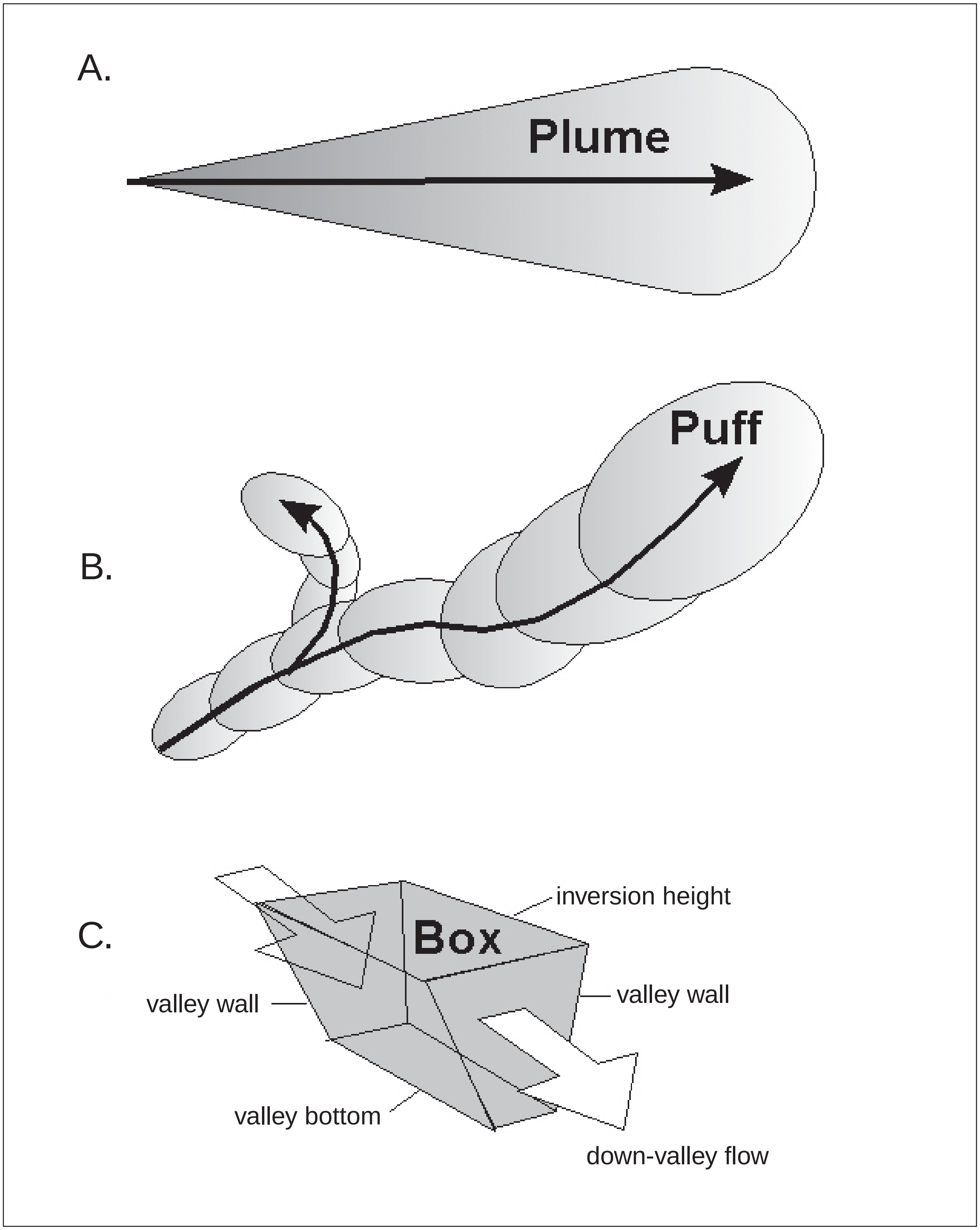


Figure 9.1. Schematic diagrams of numerical dispersion models; (A) Gaussian plume, (B) Gaussian puff, and (C) box.

sion models when understanding patterns of smoke concentrations in an isolated valley become critical.

Many grid models are called Eulerian grids because of their fixed coordinate system. The fixed coordinates make it difficult for grid models to track the impact of individual plumes but allows for easier evaluation of cumulative impacts from several plumes or chemical interactions of particles and gases within plumes. This makes grid models especially useful for evaluating the impact of smoke on regional haze. Work is underway to adapt at least two grid models (REMSAD: Systems Applications International 1998; and CMAQ: Byun and Ching 1999) for wildland fire applications. REMSAD has very simple chemistry thus is desirable for use in large domains or over long time periods. The CMAQ model is more fully physical and part of the EPA's Models 3 project, which is a "one-atmosphere" air quality modeling framework designed to evaluate all potential impacts from all known sources. At this time grid models require experienced modelers to initialize and run. Smoke managers, however, may be asked to provide input for grid models and could begin seeing results that influence application of regional haze rules.

Uncertainty

All prediction systems include some level of uncertainty, which may occur from the meteorological inputs, diffusion assumptions, plume dynamics, or emission production. Many dispersion models and methods have been compared to observations of plumes from point sources, such as industrial stacks, or tightly controlled experiments (e.g., Achtemeier 2000). In these cases, the greatest error usually occurs because of inaccuracies in the weather inputs; either from a poor forecast or an insufficient number of data points. If trajectories can be determined correctly then dispersion and resulting down-wind concentrations from point sources are relatively straightforward calculations. This is because emission rates and subsequent energy transmitted to the plume from industrial stacks, or controlled experiments, usually are constant and can be known exactly.

It is expected that the largest source of uncertainty in modeling smoke concentrations from wildland fires is in estimating the magnitude and rate of emissions. Highly variable ignition patterns and the condition and distribution of fuels in wildland fires create complex patterns of source strength. This causes plumes with simultaneous or alternating buoyant and non-buoyant parts, multiple plumes, and emission rates that are dependent on fuel availability and moisture content. Few comparisons of observations from real wildland fires to dispersion model output are available. Those that do exist are qualitative in nature and from the active phase of broadcast-slash burns (e.g., Hardy and others 1993), which tend to generate relatively well-behaved plumes.

To calculate the complex nature of source strength, components of heat and fuel (particle and gas species) must be known. For simulating wildland fires, additional information is required on: 1) the pattern of ignition, 2) fuel moisture by size of fuel, 3) fuel loading by size, 4) fuel distribution, and 5) local weather that influences combustion rates. Much of this information is routinely gathered when developing burn plans. Peterson (1987) noted that 83% of the error in calculating emissions is due to inaccurate fuel load values. Therefore, even the best burn plan data will introduce a large amount of uncertainty in predicted dispersion patterns.

The shift from burning harvest slash to using fire in natural fuel complexes for understory renovation and stand replacements has introduced another degree of uncertainty by the existence of decaying fuel and isolated concentrations of deep duff that have previously been neglected in pre-burn inventories. This has prevented emission models from accurately estimating the contribution of smoldering combustion, which is common in the porous elements of rotten wood and deep duff. Until this omission is corrected, users must manipulate source-strength models into expecting smoldering by inputting very long ignition periods and low fuel loads, which simulate the independent smoldering combustion that occurs in porous material.

Currently variable-rate emissions are determined by approximating steady-state conditions in relatively homogeneous burning segments of a fire (e.g., Sandberg and Peterson 1984; Ferguson and Hardy 1994; Lavdas 1996; Sestak and Riebau 1988) or by allowing individual fuel elements to control combustion rates (e.g., Albini and others 1995; Albini and Reinhardt 1995; Albini and Reinhardt 1997). The steady-state method has been adapted for many of the currently available puff, plume, and box models and is most useful when the pattern and duration of ignition are known ahead of time, either through planning or prediction. The fuel-element approach shows promise for calculating emissions simultaneously with ignition rates (fire spread) and may become particularly useful for coupled fire-atmosphere-smoke models, which currently are being developed.

Principal components (plume rise, trajectory, and diffusion) of all numerical dispersion models assume functions that are consistent with standard, EPA approved, industrial stack emission models. The models themselves, however, may or may not have passed an EPA approval process. Primary differences in the physics between the models appear to be the degree to which they fully derive equations. All models include some empirical coefficients, approximations, or parameterized equations when insufficient input data are expected or when faster computations are desired. The degree to which this is done varies between models and between components of each model. Note that it is not clear whether fully physical calculations of plume rise and dispersion are more accurate than approximate calculations in biomass burning because of the considerable uncertainty in the distribution and magnitude of available fuels in wildland areas.

Output

Useful output products for smoke managers are those that relate to regulatory standards, show impact to sensitive receptors, and illustrate patterns of potential impact. Regulatory standards require 24-hour averaged and 24-hour maximum surface concentrations of respirable particles at sensitive receptors. In addition, surface concentrations of carbon monoxide (CO), lead, sulfur oxides (SOx), ozone (O_3), nitrous oxides (NOx), and hydrocarbons (e.g., methane, ethane, acetylene, propene, butanes, benzene, toluene, isoprene) are needed to conform to health regulations. Quantifying the impact on regional haze is becoming necessary, which requires an estimate of fine particles, carbon gases, NOx, O_3, relative humidity, and background concentrations. Safety considerations require estimates of visibility, especially along roads (Achtemeier et al. 1998) and at airports. In addition to quantitative output, it is helpful to map information for demonstrating the areal extent of potential impact because even the smallest amount of smoke can affect human values, especially when people with respiratory or heart problems are in its path. For example, studies have shown that only 30 to 60 $\mu g/m^3$ in daily averaged PM_{10} (particulate matter that is less than 10 micrometers in diameter) can cause increases in hospital visits for asthma (Schwartz et al. 1993; Lipsett et al. 1997). These values are less than 1/3 of the national ambient air quality standard (U.S. Environmental Protection Agency 1997). Sometimes the mere presence of smoke, regardless of its concentration, is enough to force alteration of a burn plan.

The old adage, "you can't get out what you don't put in," aptly describes the output of dispersion prediction systems. In a geometric screening system (Wade 1989), only place of impact can be approximated because elemental constituents of the source emissions are not considered. The value in screening processes of this type, however, is that they allow an objective, first-guess estimate of smoke impacts so alternative measures can be taken if needed. Also, the process can be done on a map that illustrates potential receptors and estimated trajectory for others to see and discuss. Depending on the state or tribal implementation plan, a geometric screening may be all that is needed to conform to regulatory standards.

Numerical models disperse gases and particulates that are available from a source-strength model, which uses measured ratios of emissions to amount of fuel consumed (emission factors). Emission factors vary depending on fuel type, type of fire (e.g., broadcast slash, pile, or undisturbed) and phase of the fire (e.g., flaming or smoldering). Currently, emission factors available for wildland fire include total particulate matter (PM), particulate matter that is less than 10 micrometers (μm) in diameter (PM_{10}), particulate matter that is less than 2.5 μm in diameter ($PM_{2.5}$), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), and non-methane hydrocarbons (NMHC). Emission factor tables (AP-42) are maintained by the U.S. Environmental Protection Agency (1995).

At this time, emissions of lead and SOx from biomass fires are considered negligible. Emission factors of NOx are uncertain and have not been quantified to a satisfactory level. It is assumed that ozone is not created at the source but develops downwind of the source as the plume is impacted by solar radiation. Currently, aside from grid models, only one dispersion model (CALPUFF: Scire and others 2000a) includes simple photochemical reactions for calculation of down-wind ozone.

Desired attributes within a dispersion prediction system vary in complexity by several orders of magnitude. To help potential users determine which systems may best apply to their specific need, three levels of complexity were estimated for each desired attribute as shown in table 9.3. The 1st level is the simplest; usually producing generalized approximations. At the 3rd level, attributes are determined with the best available science and often include a number of perspectives or options for output.

Using the estimated levels of complexity from table 9.3, it becomes possible to rank dispersion prediction systems for each potential application. For example, if graphical output is available, the location of impact can be determined. If surface concentrations of particles and gases are available, then the system can be used to determine health and visibility impacts. A quick estimate of visibility may require only a 1st level of complexity, while precise visibility determinations may require more complex approaches. A summary of attributes for each dispersion prediction system is provided in table 9.4. The numbers in the attribute columns refer to an estimated level of complexity from 1 to 3 as summarized in table 9.3. Ease of use is a subjective determination based on the work of Breyfogle and Ferguson (1996). It considers the number and type of inputs, the availability of inputs, required user knowledge, and effort needed to produce useful results. Because calculating a ventilation or clearing index is simply a product of two numbers, dispersion indexes typically are computed by others, and both commonly are available through fire weather or air quality forecasts, they are considered very easy to use.

Several methods/models can show cumulative impacts from a number of fires by generalizing the atmosphere's capacity to hold the total emissions (index values) or by displaying multiple plumes at once (VSmoke-GIS if separate projects are used as overlays, NFSpuff, TSARS+, and CALPUFF). The ability to numerically determine the cumulative impact, however, requires concentrations of intersecting plumes to be added together. Currently CALPUFF (Scire and others 2000a) is capable of additive concentrations.

Only two of the currently available models are specific to a geographic area. They are NFSpuff (Harrison 1995) and PB-Piedmont (Achtemeier 1994, 1999, 2000) that were built for ultimate ease by including digital elevation data so the user would not have to find it or adjust for different formats. Early versions of the NFSpuff model contain only elevation data from Washington and Oregon while later versions include all of the western states. The PB-Peidmont model includes data for the piedmont regions of

Table 9.3. Desired attributes of dispersion prediction systems are compared to estimated levels of complexity.

Attribute	1st Level	2nd Level	3rd Level
Communication Aids	Tables	Mapped concentrations	Mapped concentrations as time-sequence loops
Location of impact	At defined receptors	Maps of plume patterns	Maps of plume patterns overlain with sensitive receptor/area locations
Heath Effects	PM surface concentrations	Surface concentrations of $PM_{2.5}$ & CO	Surface concentrations of $PM_{2.5}$, CO, CH_4, NMHC
Visibility in Plume	TSP[a], relative humidity	TSP, relative humidity, $PM_{2.5}$, carbon, background	TSP, relative humidity, $PM_{2.5}$, O_3, carbon, background, NO_2
Regional Haze	Wind, mixing height, emissions	Wind, mixing height, emissions, background, TSP, relative humidity	Wind, mixing height, emissions, background, TSP, relative humidity, $PM_{2.5}$, O_3, carbon, NO_2
Complex Terrain	Generalized or specific to individual valley or basin	Spatial topography	Spatial topography, land-water, vegetation cover

[a] TSP – total suspended particles

Table 9.4. Dispersion prediction systems designed for wildland fire applications. Attributes are ranked by their level of complexity, with 1 being simplest and 3 being most complex, where a dash indicates that the attribute is unavailable. Ease of use is ranked from 1 being the easiest to 10 being the most difficult.

Type	Method/Model	Comm. Aid	Impact location	Health	Visibility in plume	Haze	Complex terrain	Ease of use
Approx.	Ventilation Index [a]	--	--	--	--	1	1	1
	Dispersion Index	--	--	--	--	1	1	1
	Geom. Screen	2	1	--	--	--	1	3
Box	ValBox	2	1	1	[b]	-	1	5
Plume	Sasem [a]	1	1	2	1	--	--	4
	Vsmoke	1	1	2	1	--	--	5
	Vsmoke-GIS	2	3	2	1	--	--	6
Puff	NFSpuff	3	2	2	[b]	--	2	5
	Citpuff/TSARS+	2	2	2	[b]	--	2	9
	CALPUFF [a]	3	3	3	2	--	3	8
Particle	PB-Piedmont	2	2	-	-	-	1	5

[a] Most likely to meet regulatory requirements (varies from state to state and tribe to tribe)
[b] Although not a direct output of the model, visibility may be approximated from concentration (Wade 1988)

southeastern United States. Other models do not require elevation data (e.g., SASEM and VSmoke) or allow the input of elevation data from anywhere as long as it fits the model-specified format (e.g., VSmoke-GIS, TSARS+, and CALPUFF). While there is some concern that version 1.02 of the Emission Production Model (EPM: Sandberg and Peterson 1984) is specific to vegetation types in Washington and Oregon, it has been adapted for use in the southeastern U.S. through VSmoke (Lavdas 1986) and can be adjusted to function elsewhere in the country (e.g., SASEM: Sestak and Riebau 1988). Newer versions of EPM (Sandberg 2000) and the BurnUp emissions model (Albini and Reinhardt 1997) are not geocentric but to date neither has been incorporated into any available dispersion prediction system.

Summary

For many projects a simple model often provides as good information as a more complex model. Regulations, however, may dictate the level of modeling required for each project. Other times, community values will determine the level of effort needed to demonstrate compliance or alternatives. Also, skills available to set up and run models or the availability of required input data may affect whether a prediction system is necessary and which one is most appropriate.

Because regulations vary from state to state and tribe to tribe and because expectations vary from project to project there is no simple way to determine what dispersion prediction system is best. It is hoped that the information in tables 9.3 and 9.4 can be used to help assess the value of available methods and models. For example, if a simple indication of visibility impacts is required, plume models can be used or visual indexes can be approximated from concentrations out of box, plume, or puff models. If more detailed visibility impacts are required, a sophisticated puff model should be used. Whatever the situation, whether smoke dispersion prediction systems are used for screening, planning, regulating, or simply game playing, it is helpful to remember their strengths and weaknesses.

Literature Citations

Achtemeier, G.L. 1994. A computer wind model for predicting smoke movement. South. J. Appl. Forest. 18: 60-64.

Achtemeier, G.L. 1999. Smoke Management: Toward a Data Base to Validate PB-Piedmont - Numerical Simulation of Smoke on the Ground at Night Proceedings of the 1999 TAPPI Internatinal Enviromental Conference, April 18-21, 1999, Nashville, Tennessee, Opryland Hotel, Vol. 2.

Achtemeier, G.L. 2000. PB-Piedmont: A numerical model for predicting the movement of biological material near the ground at night. In: Proceedings of the 24th conference on agricultural and forest meteorology; 14-18 August 2000; Davis, CA. Boston, MA: American Meteorology Society: 178-179.

Achtemeier, G.L., W. Jackson, B. Hawkins, D.D. Wade, and C. McMahon. 1998. The smoke dilemma: a head-on collision! Transactions of the 63rd North American Wildlife and Natural Resource Conference. 20-24 March 1998. Orlando FL. 415-421.

Albini, F.A., J.K. Brown, E.D. Reinhardt, and R.D. Ottmar. 1995. Calibration of a large fuel burnout model. Int. J. Wildland Fire. 5(3): 173-192.

Albini, F.A. and E.D. Reinhardt. 1995. Modeling ignition and burning rate of large woody natural fuels. Int. J. Wildland Fire. 5(2): 81-91.

Albini, F.A. and E.D. Reinhardt. 1997. Improved calibration of a large fuel burnout model. Int. J. Wildland Fire. 7(2):21-28.

Breyfogle, Steve and S. A. Ferguson. 1996.User assessment of smoke-dispersion models for wildland biomass burning. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. PNW-GTR-379. 30 pp.

Byun, D.W. and Ching, J.K.S., editors. 1999. Science Algorithms of the EPA Models-3 Community Multiscale Air Quality (CMAQ) Modeling System. U.S. Environmental Protection Agency, Office of Research and Development. EPA/600/R-99/030. pages unknown.

Ferguson, S.A; Hardy, C.C. 1994. Modeling Smoldering Emissions from Prescribed Broadcast Burns in the Pacific Northwest. International Journal of Wildland Fires 4(3):135-142.

Ferguson, S.A.; S. McKay; D. Nagel; T. Piepho; M.L. Rorig; and C. Anderson. 2001. The potential for smoke to ventilate from wildland fires in the United States. In Proceedings of the 4th Symposium on Fire and Forest Meteorology, 13-15 November 2001, Reno, Nevada. Paper No. 4.6.

Hardy, C.C.; Ferguson, S.A.; Speers-Hayes, P.; Doughty, C.B.; Teasdale, D.R. 1993. Assessment of PUFF: A Dispersion Model for Smoke Management. Final Report to USDA Forest Service Pacific Northwest Region. Fire and Environmental Research Applications, USDA Forest Service, PNW Research Station, 32 pp.

Harrison, H. 1995. A User’s Guide to PUFFx: A Dispersion Model for Smoke Management in Complex Terrain. WYNDSoft Inc., 42 pp.

Hummel, J.; Rafsnider, J. 1995. User’s Guide: TSARS Plus Smoke Production and Dispersion Model, Version 1.1. National Biological Service and the Interior Fire Coordination Committee. 107 pp.

Harms, Mary F.; Lavdas, Leonidas G. 1997. Draft: User’s Guide to VSMOKE-GIS for Workstations. Research Paper SRS-6. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 41 p.

Lavdas, L.G. 1982. A day/night box model for prescribed burning impact in Willamette Valley, Oregon. Journal of Air Pollution Control Agency, 32:72-76.

Lavdas, L.G. 1986. An Atmospheric Dispersion Index for Prescribed Burning. U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. RP- SE-256. 35 pp.

Lavdas, L.G. 1996. VSMOKE User's Manual. U.S. Department of Agriculture, Forest Service, Southern Research Station. GTR-SRS-6. 147 pp.

Lipsett M., Hurley S., Ostro B. 1997. Air Pollution and Emergency Room Visits for Asthma in Santa Clara County, California. Environmental Health Perspectives. 105(2):216-222.

Ottmar, R.D., M.F. Burns, J.N. Hall, and A.D. Hanson. 1993. CONSUME User's Guide. Gen. Tech. Rep. PNW-GTR-304. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR. 117 pp.

Peterson, J.L. 1987. Analysis and reduction of the errors of predicting prescribed burn emissions. Master of Science thesis. University of Washington, Seattle, Washington. 70 pp.

Ross, D.G.; Smith, I.N.; Mannis, P.C.; Fox, D.G. 1988. Diagnostic wind field modeling for complex terrain: model development and testing. Journal of Applied Meteorology, 27:785-796.

Reinhardt, E.D., R.E. Keane, and J.K. Brown. 1997. First Order Effects Model: FOFEM 4.0 User's Guide. Gen. Tech. Rep. INT-GTR-344. U.S. Department of Agriculture, Forest Service, Intermountain Research Station. Ogden, UT. 65 pp.

Sandberg, D.V.; Peterson, J. 1984. A source strength model for prescribed fires in coniferous logging slash. Presented at the 1984 Annual Meeting, Air Pollution Control Association, Pacific Northwest Section, 1984 November 12-14, Portland, Oregon. 10 pp.

Sandberg, D.V. 2000. Implementation of an improved Emission Production Model. Abstract. Joint Fire Science Program Principle Investigator's Meeting. 3-5 October 2000, Reno, NV.

Schaaf, M.D., J. Nesbitt, and J. Hawkins. 1999. An introduction to smoke emissions and dispersion modeling. National Interagency Fire Center, Great Basin Training Unit, 17-19 March, 1999, Boise Idaho. CH2Mhill, Portland, OR. [unpaginated].

Schwartz J, Slater D, Larson T.V, Pierson W.E, Koenig J.Q. 1993. Particulate air pollution and hospital emergency room visits for asthma in Seattle. Am Rev Respir Dis. 147(4):826-831.

Scire, J.; Strimaitis, D.G.; Yamartino R.J.; Xiaomong Zhang. 2000a. A User's Guide for CALPUFF Dispersion Model (Version 5). Earth Tech, Inc., Concord, Massachusetts. 512 pp.

Scire, J.; Robe, F.R.; Fernau, M.E.; Yamartino, R.J. 2000b. A User's Guide for CALMET Meterorological Model. Earth Tech, Inc., Concord, Massachusetts. 332 pp.

Sestak, M.L.; Marlatt,W.E.; Riebau, A.R. Unpublished. Draft VALBOX: Ventilated Valley Box Model; U.S. Bureau of Land Management, 32 pp.

Sestak, M.L.; Riebau, A.R. 1988. SASEM, Simple Approach Smoke Estimation Model. U.S. Bureau of Land Management, Technical Note 382, 31 pp.

South Carolina Forestry Commission. 1996. Smoke Management Guidelines for Vegetative Debris Burning Operations: State of South Carolina. SCFC 3rd Printing. 19 pp.

Systems Applications International. 1998. User's Guide to the Regulatory Modeling System for Aerosols and Deposition (REMSAD). SYSAPP98-96/42r2, prepared for the U.S. EPA under contract 68D30032. Available on U.S.EPA website at <www.epa.gov/scram001/>.

USDA Forest Service, Southern Forest Experiment Station. 1976. Southern forestry smoke management guidebook. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. SE-10. 55 pp.

U.S. Environmental Protection Agency. 1995. Compilation Of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, (AP-42). Fifth edition. Office of Air Quality Planning and Standards Office of Air and Radiation, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711. [unpaginated].

U.S. Environmental Protection Agency. 1997. National Ambient Air Quality Standards for Particulate Matter; Final Rule. 40 CFR Part 50 [AD-FRL-5725-2] RIN 2060-AE66. Federal Register. 62(138): 102 pp.

Wade, D.D. 1989. A Guide for prescribed fire in southern forests. National Wildfire Coordinating Group, Prescribed Fire and Fire Effects Working Team, Boise Interagency Fire Center, ATTN: Supply, 3905 Vista Avenue, Boise, ID 83705. NFES #2108. [U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. Tech. Pub. R8-TP 11.] 56 pp.

Chapter 10

AIR QUALITY MONITORING

Air Quality Monitoring for Smoke

John E. Core

Janice L. Peterson

Introduction

There are several reasons why wildland fire managers may want to conduct an ambient air quality-monitoring program. These include:

- smoke management program evaluation purposes,
- to fulfill a public information need,
- to verify assumptions used in Environmental Assessments,
- to assess potential human health affects in communities impacted by smoke,
- and to evaluate wildland burning smoke impacts on State and Federal air quality laws and regulations.

Both visibility data and $PM_{10}/PM_{2.5}$ concentration data are useful to smoke management program coordinators for assessing air quality conditions if the information is provided in real-time. Fire managers may also be interested in monitoring impacts on visibility in Class I areas. Whatever the objective may be, care must be taken to match monitoring objectives to the right monitoring method. Monitoring locations, sampling schedules, quality assurance, and monitoring costs are elements that must also be considered.

Particulate Monitoring Techniques

Particulate monitoring instruments generally use one of two particle concentration measurement techniques: gravimetric or optical. Gravimetric or filter-based instruments collect particulates on ventilated filters. The filters are later weighed at special laboratory facilities to determine the mass concentration of particulate collected. Gravimetric monitoring techniques have been used for years to quantify mass concentration levels of airborne particulate matter. Filter-based sampling is labor intensive. Filters must be conditioned, weighed before sampling, installed and removed from the instrument, and reconditioned and weighed again at a special facility. Results may not be available for days or weeks. Also, airflow rates and elapsed sampling time must be carefully monitored and recorded to ensure accurate results. Filter-based techniques integrate samples over a long period of time, usually 24-hours, to obtain the required minimum mass for analysis. Gravimetric monitoring is best for projects where high-accuracy is needed and the time delay in receiving the data is not a problem. State monitoring networks designed to detect violations of air quality standards rely largely on gravimetric monitors. Specific monitoring devices must be approved by EPA for this task and are called Federal Reference Monitors (FRM's).

Optical instruments measure light-scattering (nephelometers) or light-absorbing (aethalometers) characteristics of the atmosphere. This measurement can then be converted to obtain an estimate of the concentration of airborne particulates. Optical instruments offer several advantages over gravimetric methods, including real-time readings, portability, low power consumption, and relatively low cost. Optical instruments have the disadvantage of being generally less accurate than gravimetric instruments at estimating particulate mass concentration. Optical instruments are best for projects where real-time or near-real time data is needed, where a high degree of accuracy is not a requirement, and if instrument portability and ruggedness is desirable.

Proper conversion of the light scattering measurement collected by nephelometers to an estimate of particle concentration requires development of customized conversion equations. The light scattering value measured depends on particle size distribution and optical properties of the specific aerosol mix in the area of interest. The light scattering value measured varies as a function of the relative proportions of fine particles (including smoke) and coarse particles (such as soil dust). As a result, optical instruments should be calibrated against a co-located FRM in the same area, and pollutant mix, in which they will eventually operate. A formula is then developed to properly convert scattering to a particulate mass per unit volume ($\mu g/m^3$) estimate.

In a recent monitoring instrument evaluation study, sixty-six laboratory measurements were made with the MIE DataRam, the Radiance Research nephelometer, and an EPA FRM sampler where the instruments were exposed to pine needle smoke (Trent and others 1999). Results from these tests concluded that both nephelometers overestimated mass concentrations of smoke when using the scattering to mass conversion factors provided by the manufacturer. A follow-up study (Trent and others 2000) compared optical instruments from various manufacturers (Radiance, MIE, Met One, Optec, and Andersen) to FRM instruments both in the field and laboratory and developed preliminary custom calibration equations (figure 10.1). The report provides an estimate of a conversion equation for each instrument tested

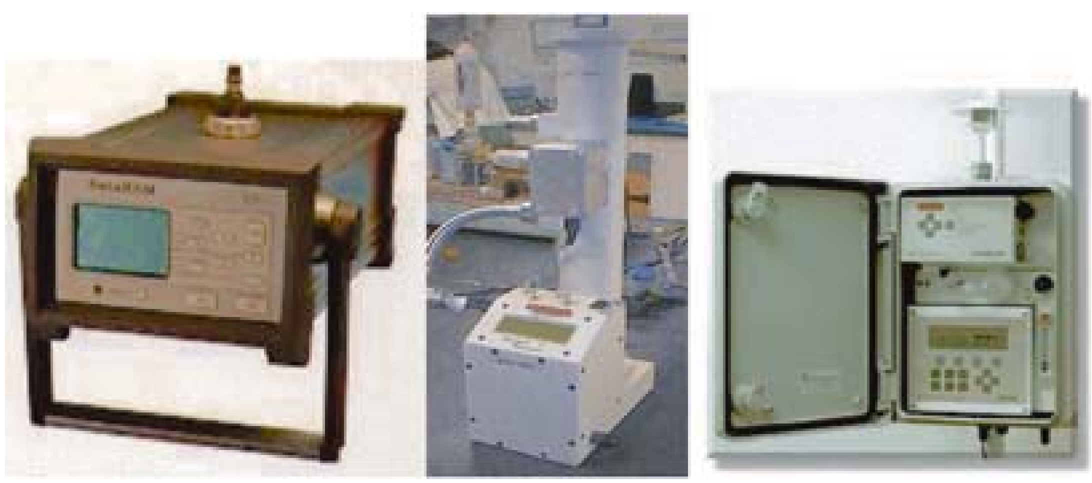


Figure 10.1. Three of the nephelometers tested during the Trent and others (2000) study include the MIE DataRam, the Radiance Research nephelometer, and the Met One GT-640.

but also recommends that optical instruments be field calibrated for a type of fire event, and that meteorological conditions and existing levels of ambient particles be included. Specific conditions to consider during calibration are age of the smoke, type of fire (flaming or smoldering), fuel moisture, relative humidity, and background particle concentration without smoke from the fire. Figure 10.2 shows the correlation found between $PM_{2.5}$ measurements made with an EPA FRM gravimetric instrument vs. results from an MIE DataRam nephelometer (Trent and others 2000).

Wildland Fire Smoke Monitoring Objectives

Gathering PM_{10}/$PM_{2.5}$ air quality data downwind from a prescribed burn or wildfire is an important fire manager goal in some areas. This data may be used as an input to smoke management decision-making, and may or may not involve immediate public release of estimated pollutant levels and health warnings. This monitoring can be conducted at a few sensitive locations within a relatively small area during specific events such as a planned large-scale understory burn, or used as a permanent part of smoke management effectiveness monitoring. Real-time data access, ease of use, and ruggedness are all generally required so optical instruments are most appropriate (table 10.1). Monitors are often equipped with data loggers and modems to permit downloading of the data over a telephone line or via radio modem. In the near future, technology will be available to make air quality monitoring data from remote sites accessible over the Internet. The USDA Forest Service, Missoula Technology and Development Program with Applied Digital Security, Inc have developed a satellite-based data retrieval system. Appropriately outfitted

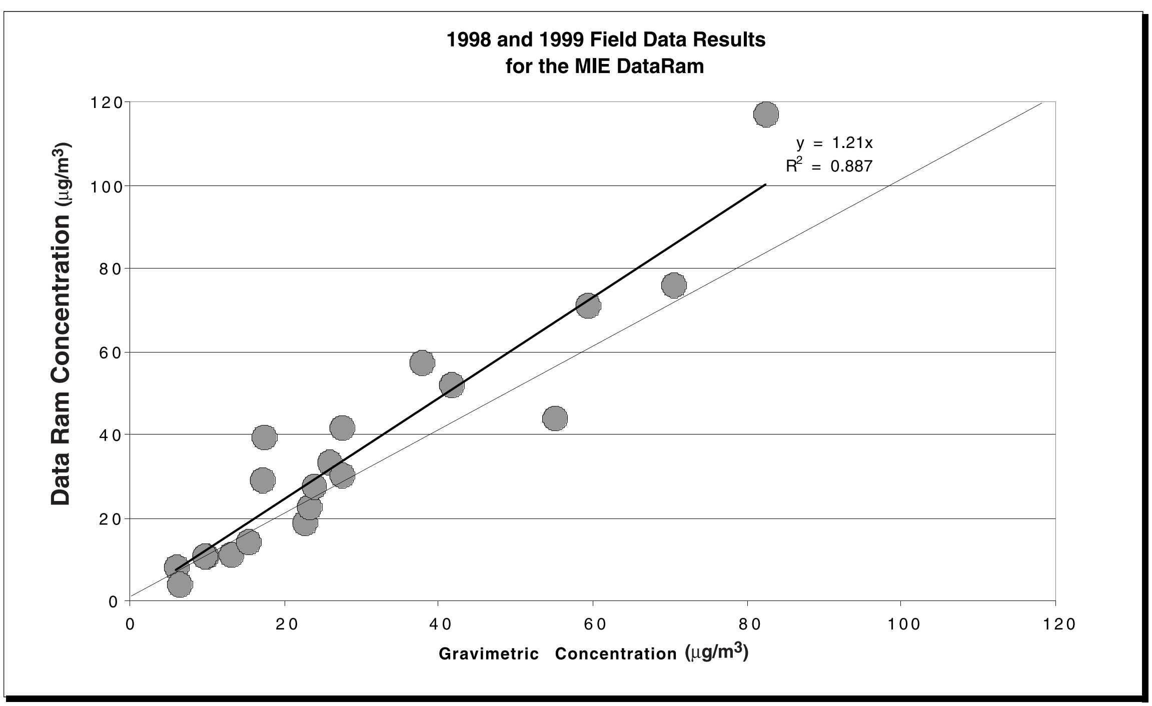


Figure 10.2. Comparison of $PM_{2.5}$ measurements made with a gravimetric Federal Reference Monitor vs. an MIE DataRam nephelometer (Trent and others 2000).

Table 10.1. Equipment appropriate for smoke monitoring differs by program objective.

Program objective	Temporal requirement	Spatial scale or extent	Applicable monitoring equipment
Smoke impact monitoring	Real-time, short-term or event-based	Localized, neighborhood-to-urban scale	▪ Radiance nephelometer[a] ▪ MIE DataRAM nephelometer[b] ▪ Laser photometers[c] ▪ TEOM[d] ▪ BAM[e]
NAAQS monitoring	Long-term	Urban to broad airshed scale	▪ MiniVols[f] ▪ Dichots[g] ▪ Other EPA FRM Monitor[h]
Visibility monitoring	Long-term and real-time	Regional	▪ IMPROVE Sampler[i] ▪ Optec Nephelometer[j] ▪ 35mm Camera[k] ▪ Digital Camera System[l]

[a] A small, lightweight, battery powered integrating nephelometer is manufactured by Radiance Research. Like all light scattering devices, the extinction measurements made by this instrument may be used to estimate PM10/PM2.5 mass by applying an appropriate conversion formula to the light scattering measurements. Units cost about $4,800.

[b] The MIE DataRam nephelometer internally estimates mass concentration via a default or user-specified conversion formula. Units cost about $11,000.

[c] Laser photometers are small, battery powered light scattering devices that provide real-time estimates of light extinction, which can then be converted to PM10/PM2.5 mass given the appropriate conversion formula. Manufacturers include Met One Instruments Inc. and TSI. Units cost about $5,300.

[d] Tapered Element Oscillating Microbalance (TEOM). Manufactured by Rupprecht & Patashnick. The TEOM is an EPA Equivalent Method designated for PM_{10}. Cost is about $17,000.

[e] The Beta Attenuation Monitor (BAM) is also known as a Beta Gauge Monitor. Manufactured by Thermo Environmental, Graseby Andersen, and Dasibi Environmental Corporation. These are EPA Equivalent Methods designated for PM_{10}. Costs range from $14,000 to $20,000.

[f] The MiniVol Portable Air Sampler is a filter-based instrument that utilizes rechargeable batteries, a small air pump, and a programmable timer. Manufactured by Airmetrics, Inc., units cost about $2,300.

[g] The dichotomous sampler (dichot) is a filter-based system manufactured by Graseby Andersen that collects both coarse (2.5-10 µm) and fine particles (<2.5 µm) for speciation analysis. Units cost about $8,500.

[h] EPA federal reference method (FRM) samplers for PM10 and PM2.5 include the Rupprecht & Patashnick Partisol and Partisol-Plus Sequential Sampler; the BGI portable PM10 sampler, the Andersen Instruments RAAS FRM PM2.5 sampler and others. See the EPA AMTIC web page for current information.

[i] The IMPROVE Modular Aerosol Sampler ($35,000) is a filter-based unit manufactured by Air Resource Specialists. It consists of PM10 and PM2.5 sampling heads which capture aerosols on Teflon and quartz filters for chemical analysis (speciation). Costs range from $6,500 to $26,000 depending on configuration.

[j] For true ambient light scattering measurements, the NGN-2 nephelometer manufactured by Optec ($25,000) and used in the IMPROVE network is the standard instrument for visibility monitoring.

[k] A 35mm camera with auto winder, data back and enclosure used for scene monitoring costs about $3,300.

[l] One digital image acquisition system is available from Air Resource Specialists, Inc. and includes a digital camera, weatherproof enclosure, and image capture computer. The system costs approximately $4,800.

instruments will send packets of 5-minute average particulate concentrations each hour by satellite to a stored database to be viewed and retrieved through a Web site.[1]

A second smoke monitoring objective may be to gather data on prescribed fire smoke impacts at sensitive locations over a much longer period for purposes of comparison with ambient air quality standards (NAAQS). In these cases, immediate data access is of secondary importance to gathering data that approximates or is equivalent to the high-accuracy official Federal Reference Method (FRM) instruments used by air regulatory agencies. A popular option is the small, portable, battery powered MiniVol sampler although these are not official EPA FRM designated monitors. The lag-time limitation may be overcome by using one of two EPA-approved continuous air monitoring devices (TEOM or Beta Attenuation Monitors [BAM]) but this equipment is costly and requires a high degree of technical skill to operate (table 10.1).

Visibility protection is another monitoring objective for fire managers when wildland burning smoke may impact nearby Class I areas. For visibility monitoring, information is not only needed on PM_{10}/$PM_{2.5}$ concentrations but aerosol chemical composition and particle light scattering and absorption as well. Since aerosol chemical analysis (speciation) monitoring requires filter-based methods and extinction measurements require in-situ real-time methods, a combination of techniques are used. Monitoring is typically conducted throughout the year over long time periods to establish trends. In as much as data consistency with the national visibility programs is also important, specialized instruments designed and deployed by the Interagency Monitoring of Protected Visual Environments (IMPROVE) Network (Malm

Figure 10.3. A typical IMPROVE monitor installation.

[1] MTDC Air Program News Issue 1. August 2001. Available at: http://fsweb.mtdc.wo.fs.fed.us/programs/wsa/air_news/issue1.htm

2000) should be used whenever possible (figure 10.3). Monitoring the visual quality of a vista, called scene monitoring, is often done at the same time using 35mm cameras. Digital camera systems can be used at sites where real-time web access to the scene is desirable (table 10.1).

Further monitoring guidance is available on the Internet at the EPA Air Monitoring Technology Information Center (AMTIC) web site (http://www.epa.gov/ttn/amtic) and the EPA Visibility Improvement site (http://www.epa.gov/oar/vis/index.html).

Monitoring Locations & Siting

Samplers used for smoke impact monitoring are normally placed at smoke sensitive locations that have the greatest likelihood of impact.[2] This may be a private residence, within a nearby community, or at a county fair. Care must be taken to ensure that the instrument is located in an open, exposed location removed from local pollution sources such as dirt roads, burn barrels, or woodstoves that would influence the data. The sampler should be located two or more meters above ground at a secure location. Power availability and access are often controlling considerations (CH2MHill 1997).

Visibility monitoring sites must be representative of the Class I area of interest and are therefore best located within the area's boundary or, in the case of wilderness areas, as close to the boundary as possible. Since visibility data is used to represent conditions over sub-regional spatial scales, special care is needed in siting to avoid local source influences. The IMPROVE network has recently been expanded with representative monitors for each of the 156 Class I areas in the country. Siting of the instruments was accomplished with state and Federal Land Manager input.

Sampling Schedules

The timing, duration, and frequency of sampling depend on the program objective. Continuous, hourly data is needed to monitor smoke impacts from several days prior to burn ignition to a day or two after the event. In contrast, PM_{10} NAAQS compliance monitoring using filter-based instruments is conducted once every six days in attainment areas. In a nonattainment area, daily sampling is required for cities with more than a million people and every three days otherwise. Filter-based measurements made as part of the IMPROVE visibility monitoring network are made every third day to reduce costs and operational requirements. Continuous monitoring instruments always operate 24 hours per day. Although sampling duration and frequency decisions are often based largely on operating costs and technician time requirements, measurements made as part of the IMPROVE network or for NAAQS compliance determinations must follow the protocols outlined in EPA regulations found on the AMTIC web site.

[2] For NAAQS compliance monitoring, refer to the EPA Monitoring Network Siting Guidance found on the EPA AMTIC web site at: http://www.epa.gov/ttn/amtic.

Quality Assurance

Data integrity is essential in any monitoring program. Every monitoring project should have a documented quality assurance plan. In addition to the maintenance and calibration measures outlined by the manufacturer of the instruments being used, additional quality assurance measures may also be included in the plan if the monitoring data are of an especially important nature. These include auditing procedures conducted by the state/local air quality agency to verify proper instrument siting, calibration and data capture as well as traceability of measurement standards to the National Bureau of Standards (NBS) (EPA 1984). Methods of calculation and data processing should also be audited. Fire managers may wish to confer with their state/local air agency to assure that monitoring results are valid.

Monitoring Costs

Monitoring is expensive. In addition to the capital cost of the instruments, costs for equipment installation, electrical, maintenance, calibration standards, supplies, shipping, data analysis, and reporting must also be considered. In the case of filter-based particulate sampling, laboratory costs for filter weighing and chemical analysis must also be included. On-going annual operating costs for technician time to service the instruments is a major expense that often drives the monitoring system design.

Literature Citations

CH2MHill. 1997. When and how to monitor prescribed fire smoke: a screening procedure. Prepared for the USDA Forest Service, Pacific Northwest Region, Portland, OR. Contract No. 53-82FT-03-2. 49p. Available at: http://www.fs.fed.us/r6/aq.

Environmental Protection Agency. 1984. Quality assurance handbook for air pollution measurement systems. EPA-600/9-76-005. US Environmental Protection Agency, Office of Research and Development. Washington DC.

Malm, William C. 2000. Spatial and seasonal patterns and temporal variability of haze and its constituents in the United States – Report III. ISSN: 0737-5352-47. Cooperative Institute for Research in the Atmosphere. Colorado State University. Fort Collins, CO 80523.

Trent, Andy; Thistle, Harold, Fisher, Rich; [and others]. 1999. Laboratory evaluation of two optical instruments for real-time particulate monitoring of smoke. Tech. Rep. 9925-2806-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 14p.

Trent, Andy; Davies, Mary Ann; Fisher, Rich; [and others]. 2000. Evaluation of optical instruments for real-time, continuous monitoring of smoke particulates. Tech. Rep. 0025-2860-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 38p.

Chapter 11

EMISSION INVENTORIES

Emission Inventories

Janice L. Peterson

An inventory or estimate of total statewide (or some other geographically distinct unit) annual emissions of criteria pollutants is a necessary part of understanding the burden on the air resource in an area and taking appropriate control actions. Emission inventories are a basic requirement of state air resource management programs and are a required element of State Implementation Plans. Emission inventories help explain the contribution of source categories to pollution events, provide background information for air resource management, provide the means to verify progress toward emission reduction goals, and provide a scientific basis for state air programs. An accurate emissions inventory provides a measured, rather than perceived, estimate of pollutant production as the basis for regulation, management action, and program compliance. Emission inventories should include all important source categories including mobile, area, and stationary and are not complete unless difficult-to-quantify sources like agricultural burning, backyard burning, rangeland burning, and wildland and prescribed burning are each addressed.

Wildland and prescribed fires are extremely diverse and dynamic air pollution sources and their emissions can be difficult to quantify. Design and development of an emission inventory system is primarily the responsibility of state air regulatory agencies. But cooperation and collaboration between air regulatory agencies and fire managers is required to design an effective and appropriate emission inventory system. Wildland fire managers should have the knowledge and data necessary to calculate emissions from their burn programs and be prepared to work with the state in developing emission inventory systems for wildland fire.

At the most basic level, estimation of wildfire emissions requires knowledge of area burned, fuel consumed, and a fuel-appropriate emission factor. The estimate of emissions is made through simple multiplication of area burned (acres or hectares) times fuel consumed (tons per acre or kilograms per hectare) times an emission factor assigned with knowledge of the fuel type (lbs/ton or g/kg) (figure 11.1). Resulting emissions are in tons or kilograms.

Greater accuracy, precision, and complexity can be achieved through increasingly detailed knowledge of these basic parameters. For example, area burned is estimated pre-burn in many existing reporting systems; if area burned is reassessed post-burn the accuracy of the emission inventory will increase. Accuracy and precision will also be improved if fuel consumed can be estimated with knowledge of pre-burn loading and consumption of fuels in each of many possible categories based on fuel type, size, and arrangement; and with knowledge of fuel moisture conditions, weather parameters, and application of emission reduction techniques. A more precise emission factor can be assigned with knowledge of burning conditions that can shift fuel consumption from the less efficient smoldering combustion phase into the more efficient flaming phase (figure 11.2).

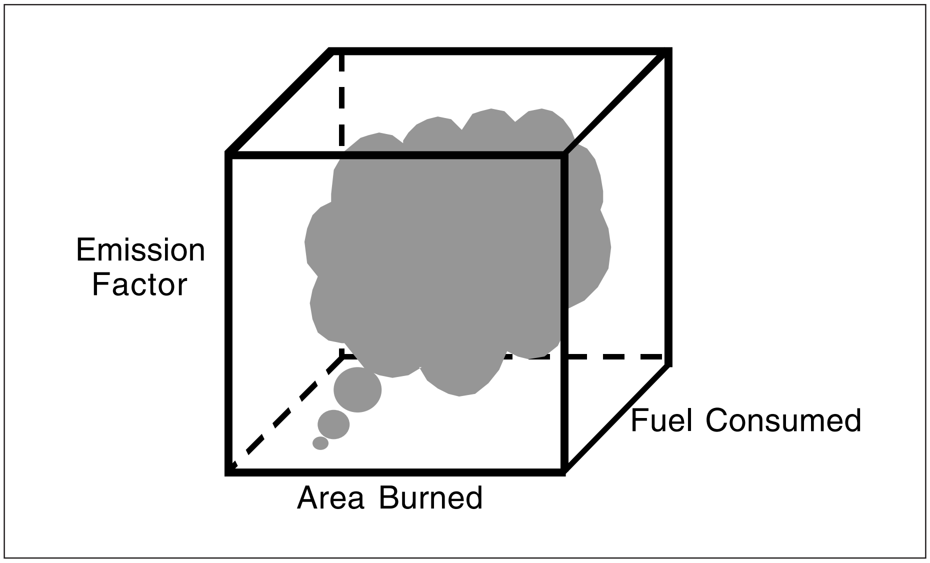


Figure 11.1. Basic information components needed to estimate the quantity of emissions from an individual wildland burn and compile an emissions inventory.

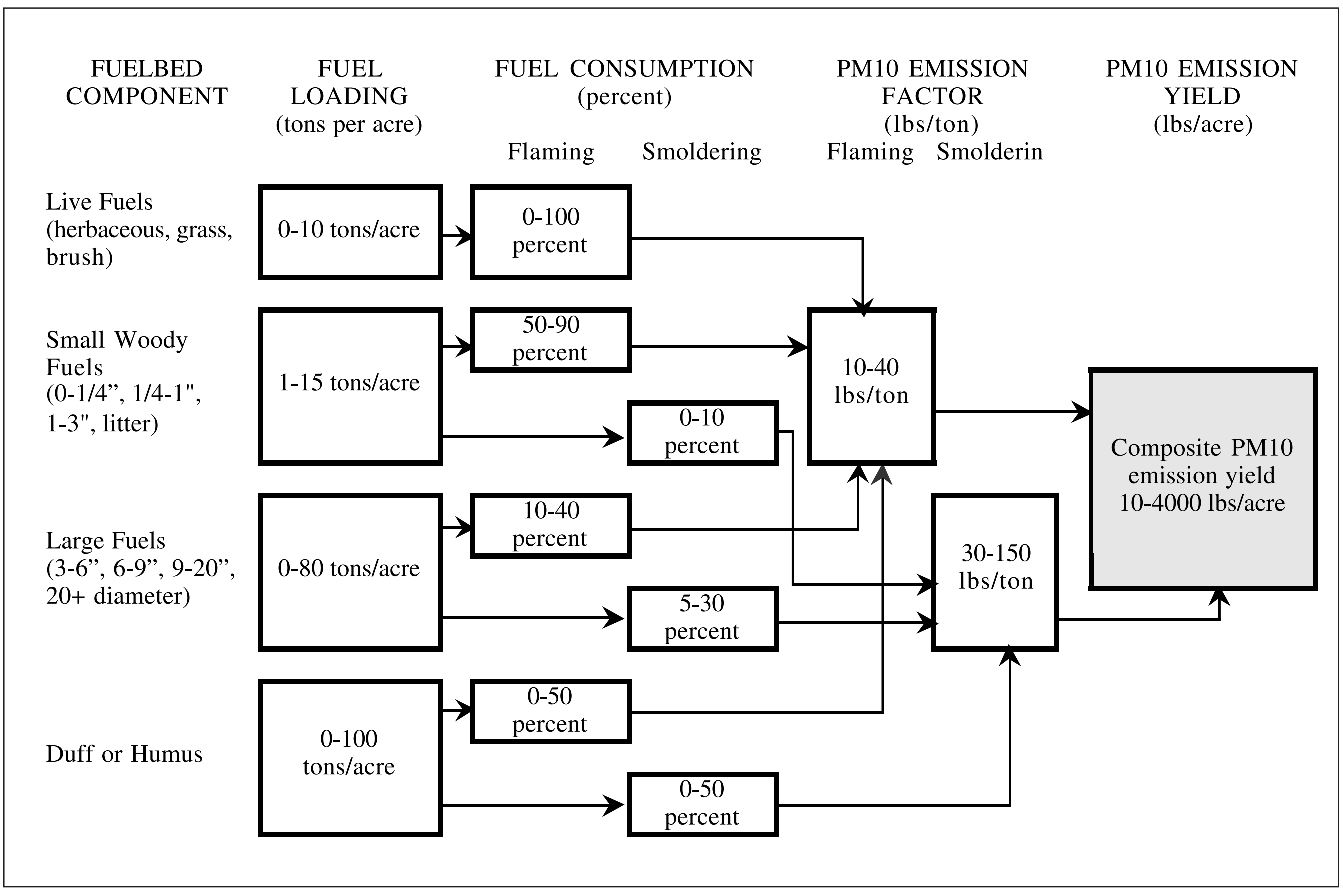


Figure 11.2. Detailed information about fuel loading and consumption by size class plus information to predict consumption by phase of combustion can increase the accuracy and precision of estimates of emissions from prescribed wildland fire for an emissions inventory (Modified from Sandberg [1988]). The ranges given in the figure cover the majority of fuel loading and consumption situations in wildland fuels but do not define the extremes. Numerous exceptions could likely be found in practice.

Sources of Prescribed Burning Activity Level Information

States with incomplete or no centralized burn reporting requirements will need to go to the burners themselves to quantify activity level. Federal agencies generally keep fairly accurate records of burning accomplished in a given time period and can also provide estimates of wildfire acres. Federal agencies that may need to be contacted in a given state or area include the Bureau of Land Management, Bureau of Indian Affairs or individual Tribes, National Park Service, Forest Service, and Fish and Wildlife Service. In some areas other federal agencies may need to be contacted. Such as the Department of Energy, Department of Defense, Natural Resources Conservation Service, Agricultural Research Service, U.S. Geological Survey, or the Department of Reclamation along with managers of National Preserves and National Monuments.

Specific state agencies with a forestry, wildlife, conservation, or natural resource management mandate are another source of activity level information. They may use prescribed burning themselves and may compile burning statistics for state lands and sometimes also for private lands. Private land owners, especially those managing timber-lands should be contacted as should The Nature Conservancy and the Audubon Society.

In some areas, especially where prescribed wildland burning is infrequent, the only source for activity level information may be a gross estimate for all prescribed fires for an entire state or area. This can sometimes be obtained from a single federal or state agency, or sometimes from an academic institution.

Type of Burn

Prescribed burning can be divided into categories depending on the arrangement of the fuels. Fuel arrangement can help predict total fuel consumption and the proportion consumed in the flaming vs. smoldering phases. Broadcast burning refers to fuels burned in place. This term can be used to describe natural woody fuels scattered under a stand of trees, woody debris scattered at random after a timber sale, brush burned in place, or grass. Fuels can also be concentrated into piles before burning. In addition to pile and broadcast burning, other general prescribed-fire-type categories that may be used include range, windrow, right-of-way, spot, black line, jack-pot, and concentration. Knowledge of the type of burn is valuable for estimating emissions as it can affect the accuracy and correct interpretation of estimates of area burned, fuel consumed, and assignment of an appropriate emission factor.

Area Burned

Area burned is generally the easiest parameter to obtain from fire managers. One caution is that area burned is often estimated prior to prescribed burning and not updated with the results of the burn, which may be smaller or larger (in the case of an escaped fire) than originally estimated. Also, area burned may reflect the area treated or the area within the wildland fire perimeter, rather than the area actually blackened by fire. The wildland fire perimeter may be considerably larger than the area actually blackened by fire. For example, a study of the Yellowstone fires of 1988 found that about 65% of the wildfire perimeter area within the park was actually blackened (Despain and others 1989), the remaining 35% was in unburned islands. In the case of prescribed fire, land managers may consider a larger area to have been treated or to have benefited by the fire than was actually blackened by flames. Compiling an accurate emission inventory requires actual acres (or hectares) blackened for an accurate estimate of emissions. Caution should be used with estimates of area burned, as this parameter is more prone to systematic overestimation than any other component of emissions estimation.

Fuel Consumed

Fuel consumed is generally estimated via a two-step process; first fuel loading is estimated, then a percent consumption is applied to calculate fuel consumed. At the most basic level, a single value for both total fuel loading and consumption can be used (for example 20 tons of fuel of which 50 percent consumed). In reality, a fuelbed is a complex mix of various sizes of woody fuels (tree boles, branches, and twigs), needle and/or leaf litter, decayed and partly decayed organic matter and rotten material (generally called duff or rot), and live fuels like brush, forbs, and grass. Each of these fuelbed components contributes to the total loading and is consumed to a greater or lesser extent. For example 100 percent of woody fuels less than 1 inch in diameter may burn whereas just 30 percent of those greater than 3 inches in diameter burn. In addition, some emission reduction techniques are specific by fuelbed component. Use of a single estimate of total fuel loading and consumption will fail to capture this. To gain accuracy in the emissions inventory and the ability to track the use and effectiveness of emission reduction techniques, further detail concerning fuel loadings by fuelbed component would ideally be tracked.

One simple method for obtaining a gross estimate of fuel loading is through the use of standardized fuel models. The most widely used example is the array of National Fire Danger Rating System (NFDRS) fuel models (Deeming and others 1977). These 20 models are standardized descriptions of different fuel types that can be used with some applicability to virtually all wildlands in the US. The NFDRS fuel models were designed as predictors of fire danger rather than to characterize the wide range of potential wildland fuel loadings as would be ideal for compilation of an emissions inventory. Another commonly used set of fuel models is based on predicting fire behavior. Thirteen fire behavior fuel models are described in Anderson (1982). Since both the NFDRS and fire behavior fuel models were designed for purposes other than accurate fuel loading estimation, these models should be used with caution. In addition, the use of standardized fuel models to estimate fuel loading means that efforts to reduce fuel loading for emission reduction purposes prior to prescribed burning cannot be tracked or reflected in the emissions inventory.

Other more detailed standardized fuel models called fuel characteristic classes (FCC's) are under development (Sandberg and others 2001) that are expected to greatly improve fuel loading estimates when they reach widespread use. It is estimated that there will be a core set of 48 to 64 FCC's in common usage with as many as 10,000 available in total describing the vast range of fuel types and conditions that can exist in wildlands across the country.

The most accurate method of estimating fuel loading is to have fire managers measure it in the field. Field estimation also enables reflection of the effect of emission reduction techniques on fuel loading. The most accurate method of estimating fuel consumption is through modeling (field measurement being unreasonably difficult in virtually all cases). In the west, two fuel consumption models are commonly used for this: the First Order Fire Effects Model (FOFEM) (Reinhardt and others 1997) and Consume (Ottmar and others 1993). These two models can provide very good estimates of fuel consumption if some basic knowledge of factors influencing fuel loading and moisture are known.

Estimating fuel loading and consumption for wildfire is much more difficult than for prescribed fire. For one thing, large wildfires often burn through many different fuel types where fuel loading can range from just a couple of tons per acre to over 100 tons per acre. Also, the science of predicting fuel consumption and emissions from a fire burning in tree crowns is extremely weak. The fuel type available from wildfire report forms is generally for the point of ignition rather than a reflection of fuel on the majority of acres burned.

Emission Factors

Wildland and prescribed-fire emission factors are contained in the EPA document AP-42 (EPA 1995) and in table 5.1 in the Smoke Source Characteristics chapter. Accuracy may be gained in an emissions inventory through knowledge of the portion of fuel consumed in the two primary consumption phases: flaming and smoldering. Flaming consumption emits far less emissions per unit of fuel consumed than smoldering consumption. Estimation of the flaming vs. smoldering ratio can be obtained through fuel consumption modeling and with knowledge of some influencing factors such as rate of ignition, fuel moisture conditions, and days since rain.

Federal Agency Reporting

The Forest Service, Bureau of Land Management, Fish and Wildlife Service, National Park Service, and Bureau of Indian Affairs all have mandatory reporting requirements for wildland and prescribed fires although at present, they are all somewhat different. These reports contain some of the basic information needed to compile an emissions inventory. Within the next couple of years, all federal agencies will be moving toward a consolidated fire reporting database through implementation of the Federal Fire Policy.

Record keeping by state and private landowners is much more variable and may or may not be available to states wishing to compile an emissions inventory.

Forest Service

Forest Service forms FS-5100-29 (wildland fire) and FS-5100–29T (prescribed fire) require some of the basic inputs needed to compile an emissions inventory. The wildland fire report form requires reporting of acres burned within the fire perimeter regardless of landowner plus National Fire Danger Rating System (NFDRS) fuel model. It is significant to note that the instructions for estimating acres (USDA Forest Service 1999) specify reporting of all acres within the fire perimeter, unfortunately this value is not likely to equal acres blackened by fire. The number of acres blackened will always be less than the number of acres within the fire perimeter so use of this value without some adjustment will result in a serious systematic overestimation of acres actually burned and therefore of smoke produced. The NFDRS fuel model reported is the one in which the fire was burning at the time and place where another required element, the fire intensity level, was observed so it may or may not be representative of the majority of acres burned. Individual fire reports are collected throughout the year and can be analyzed through an electronic system called FIRESTAT (USDA Forest Service 1999).

Data collected by the Forest Service about prescribed burning that is useful for compiling an emissions inventory includes the prevailing NFDRS fuel model; the total acres plus the percent of acres burned; the preburn loading of dead fuels 0-3 inches in diameter; 3+ inches in diameter, and live; and the percent of these fuels that consumed. The prescribed fire report allows more accurate estimation of emissions since the percent of acres burned is reported and fuel loading and consumption is estimated in three categories. The Forest Service reporting system does not include estimates of duff consumption which can contribute as much as 50 percent of the emissions from a prescribed burn in certain areas under dry conditions, though is generally much less than that.

Fish and Wildlife Service

The Fish and Wildlife Service also has mandatory fire reporting requirements and uses a system called the Fire Reporting System (FRS) for data collection. The FRS requires reporting of project area size plus the actual burned area or acres blackened for both wildland and prescribed fire. It also allows multiple entries for NFDRS fuel model and links a specific area burned to each. Fuel loading is assigned based on NDFRS defaults in seven categories: dead woody fuels of diameter 0-1/4”, 1/4-1", 1-3", 3+; herbaceous; live woody; and duff. Users then specify percent consumption for each fuelbed category. Custom fuel models may also be defined. Data collected as part of the FRS provides very good information for estimating emissions from both wildland and prescribed fire on Fish and Wildlife Service burns though this is a very small part of total burning in most areas of the country with notable exceptions in the Southeastern states and Alaska.

Bureau of Land Management

The BLM reporting requirements include estimation of area burned for wildland and prescribed fire, less any unaltered areas as an estimate of acres blackened. The fire behavior fuel model that best represents the fuels in the burn area is required as is the NFDRS fuel model in the vicinity of the fire origin. The model representing fuels in the burn area is more appropriate for emissions estimation. In addition, for prescribed fire up to two fire-behavior fuel models can be selected and the percent of the burned area assigned. Fuel loading (tons per acre) and consumption (percent) can be reported in each of six fuel size classes: 0-1", 1.1-3", 3.1-9", greater than 9", shrub and herb, and litter and duff. If actual field data for fuel loading and consumption is not available, the most appropriate standard fuel loading and consumption range can be selected. Fuel loads can be assigned as light, average, or heavy for the fire behavior fuel model type and fuel consumption can be assigned as light, average, or heavy making some customization of the standard fuel models possible. The BLM reporting system also accommodates the unique requirements of estimating loading and consumption of prescribed burning of debris piles.

National Park Service

The NPS has mandatory fire reporting requirements but the information collected is of little use for emissions estimation, especially for wildland fire. For wildland fires, acres burned is required but the instructions don't specify whether perimeter acres or acres blackened is to be reported. The only required description of vegetation assigns one of three categories: commercial forest land, non-commercial forest land, or non-forest watershed which provides little or no information for estimating fuel loading and consumption. There is an optional field for input of NFDRS fuel model but how often this is used is unknown. Prescribed fire and wildland fire for resource benefit requires input of both NFDRS fuel model and a fire behavior fuel model.

Bureau of Indian Affairs

Fire reporting requirements for the BIA are similar to those for the NPS (see discussion above). One minor difference exists in the reporting of prescribed and wildland fire for resource benefits, where a fire behavior model may be input (but is not required). Further, a fire danger rating (NFDR) fuel model cannot be input.

Choosing the Appropriate Accuracy and Precision in an Emissions Inventory

The appropriate accuracy and precision for a state emissions inventory should be designed through analysis of the importance of the source in the affected area (sub-state, state, or multi-state area). Variables influencing the importance of prescribed burning as a source can be assessed through addressing issues such as:

- whether there are current impacts from prescribed fire or wildfire smoke,
- the aggressiveness of state goals for emission reduction and air quality improvement,
- the trend in burning in the local area and the rate of increase or decrease,
- a professional or financial motivation by burners to track and/or reduce emissions,
- the need to associate wildland fire emissions with specific air pollution episodes.

Tables 11.1 and 11.2 summarize information needed for a prescribed burning emissions inventory and for a wildland fire emissions inventory. Each table lists the categories of information needed to inventory emissions, proposes a minimum requirement for a basic inventory, and lists options for increasing the accuracy and precision of the inventory which may be desirable if wildland fire in the area of interest is of concern or controversial.[1]

Data requirements for producing an emissions inventory for either prescribed burning or wildland burning are very similar. They both require information about the time period of the burn, the location, the area actually burned, a description of the fuelbed, how much fuel burned, and site specific information for assigning an emission factor. A prescribed burning

[1] Sandberg, David, V.; Peterson, Janice. 1997. Emission inventories for SIP development. An unpublished technical support document to the EPA Interim Air Quality Policy on Wildland and Prescribed Fires. August 15, 1997. (Available from the authors or online at http://www.epa.gov/ttncaaa1/faca/pbdirs/eisfor6.pdf).

Table 11.1. Summary of information needed to compile a prescribed fire emissions inventory and options for increasing accuracy.

Information Needed	Units	Minimum Requirement	Overview of Options for Increasing Precision	Comments
1. Time period	time	year	season, month, day	
2. Location	n/a	administrative area	county, latitude and longitude, legal description	Latitude and longitude, and legal descriptions may be the burn start-point or mid point. All burners should be consistent.
3. Area actually burned	acres	acres	stratify by fuelbed description, area burned by time intervals (hourly or longer)	Should be retrospective to get an accurate estimate. Time interval estimates would be necessary for accurate dispersion modeling.
4. Fuelbed description	type or tons per acre	grass/brush/ forest floor/ forest crowns or slash	vegetative type, fuel model, fuel model by loading category (high/medium/low), inventoried fuel loadings	Critical for accurately estimating fuel loading and assigning an emission factor but may also be used for estimating fuel consumed. Use of BACM techniques may be detected with refined information.
5. Fuel consumed	percent or tons/acre	expert estimate	site specific information for driving predictive models	Critical variables for gaining precision will vary with fuel type and area, fuel moisture is nearly universal. Use of BACM techniques may be detected with refined information.
6. Emission factor	lbs/ton	burn average based on fuelbed description	site specific information to allow consumption to be apportioned into flaming vs. smoldering phases	Assigned based on AP-42.
7. Type of burn or fuelbed	category	none	broadcast, pile, right-of way, spot burning	Can increase accuracy of consumption estimates and emission factor assignment.
8. Purpose of Burn	category	none	ecosystem management, waste disposal, habitat enhancement, etc.	Can be useful if SIP strategies or permitting differs by purpose of burn.

Table 11.2. Summary of information needed to compile a wildland fire emissions inventory and options for increasing accuracy

Information Needed	Units	Minimum Requirement	Overview of Options for Increasing Precision	Comments
1. Time period	time	year	season; month; wildfire start, major spread, control, and declared-out dates; activity by day	Finest time resolution for which the inventory results will be used.
2. Location	n/a	administrative area	county; latitude and longitude	
3. Area actually burned	acres	acres	acres black stratified by other categories of information such as date, fuelbed, area burned in severe, moderate and low intensity, etc.	Currently, reported wildfire area burned is generally perimeter area which results in a systematic overestimation of area burned by as much as one third.
4. Fuelbed description	type or tons per acre	grass/brush/ forest floor/ forest crowns or slash	vegetative type, fuel model, fuel model by loading category (high/medium/low), percent of area burned by fuelbed description	Critical for estimating fuel loading and assigning an emission factor but may also be used for estimating fuel consumed. Unfortunately "cover type at point of ignition" is generally what is indicated on fire reports. Minimally, acres burned are to be stratified by grass, brush, forest floor, timber crowns, or slash. This is the most critically lacking variable in most current fire reports, and some approach to augmenting the information should be considered.
5. Fuel consumed	percent or tons/acre	expert estimate	more research is needed to develop algorithms to predict wildfire fuel consumption	Very difficult to estimate accurately and likely varies widely throughout a wildfire area.
6. Emission factor	lbs/ton	average value from table	see fuelbed description	Assigned based on AP-42.
7. Control strategy	category	none	full suppression, modified, limited	May be used in some SIP strategies in order to identify sources that are allowed to burn to achieve resource benefits or economic efficiency.

emissions inventory includes extra information about the type of burn or fuelbed arrangement plus the purpose of the burn. These are optional data items that may be useful in some cases. A wildland burning emissions inventory includes information about the control strategy used to fight the fire.

Literature Citations

Anderson, Hal E. 1982. Aids to determining fuel models for estimating fire behavior. USDA For. Serv. Gen. Tech. Rep. INT-122. Intermt. For. And Range Exp. Stn., Ogden, Utah. 22p.

Deeming, John E., Robert E. Burgan, and Jack D. Cohen. 1977. The National Fire-Danger Rating System – 1978. USDA Forest Service Gen. Tech. Rep. INT-39. Intermt. For. And Range Exp. Stn., Ogden, Utah. 63 p.

Despain, Don; Rodman, Ann; Schullery, Paul; Shovic, Henry. 1989. Burned area survey of Yellowstone National Park: the fires of 1988. Yellowstone National Park, WY: U.S. Department of the Interior, National Park Service, Yellowstone National Park. 14 p.

Environmental Protection Agency. 1995. Compilation of air pollutant emission factors AP-42. Fifth Edition, Volume 1, Chapter 13.1: Wildfires and prescribed burning. Supplement B, October 1996. U.S. Environmental Protection Agency, Research Triangle Park, NC.

Ottmar, Roger D.; Burns, Mary F.; Hall, Janet N.; Hanson, Aaron D. 1993. CONSUME users guide. Gen. Tech. Rep. PNW-GTR-304. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 17 p.

Reinhardt, Elizabeth D.; Keane, Robert E.; Brown, James K. 1997. First Order Fire Effects Model, FOFEM 4.0 user's guide. GTR IMT-GTR-344.

Sandberg, David V. 1988. Emission reduction for prescribed forest burning. In: Mathai, C.V.; Stonefield, David H., eds. Transactions—PM10: implementation of standards: An APCA/EPA International Specialty Conference; 1988 February 22-25; San Francisco: 628-645.

Sandberg, David V.; Ottmar, Roger D., Cushon, Geoffery H. 2001. Characterizing fuels in the 21st century. International Journal of Wildland Fire 10:1-7.

USDA Forest Service. August 1999. FIRESTAT 5.0 User's Guide. Fire and Aviation Management. Washington DC.

Chapter 12

ADMINISTRATION AND ASSESSMENT

Smoke Management Program Administration and Evaluation

Peter Lahm

Smoke management program administration can range from activities conducted at the local burn program level to a multi-state coordinated effort to manage smoke. The EPA Interim Air Quality Policy on Wildland and Prescribed Fires (Interim Policy) (EPA 1998) recommends that smoke management programs be administered by a central authority with clear decision-making capability. As smoke management programs range from voluntary efforts to mandatory regulatory driven programs, the administration will vary accordingly[1]. On the more local level, the programs may be administered by a group of land managers or private landholders seeking to coordinate burning efforts to avoid excessive smoke impacts. Mandatory regulatory driven smoke management programs tend to be administered by tribal/state/district air quality regulatory agencies or state forestry entities. The administration of smoke management programs allows for a number of different approaches to meet EPA objectives and to maintain cooperative and interactive efforts to manage the dual objectives of good air quality and land stewardship.

The Interim Policy also recommends periodic evaluation of smoke management programs to ensure that air quality objectives are being met. From the land management point of view, these same reviews are critical to assessing whether land management objectives are being met under the smoke management program. EPA also recommended periodic evaluation of smoke management rule or regulation effectiveness as part of its Interim Policy. For programs that are under scrutiny by a concerned public or are growing rapidly, continuous evaluation should also be considered. All smoke management efforts—from formal interagency smoke management plans to less structured efforts to address smoke from individual fire operations—can benefit from continuous and periodic evaluation. If a smoke management program changes size, jurisdiction, or regulatory responsibilities, the level of effort applied to managing smoke should also change. To keep a program ahead of growing air quality concerns, a continuous effort to evaluate smoke management effectiveness is useful. This evaluation is also critical for local unit programs that are under formal state or tribal smoke management plans. The evaluation process has applicability to all types of fire, including wildland fire under suppression, wildland fire use and prescribed fire.

[1] Examples of specific state smoke management programs are provided in chapter 4, section 4.2.

Smoke Management Program Administration

Administration of a smoke management program is frequently a function of the size of the burn program using a metric such as acres burned or emissions generated, coupled with the complexity of the local air quality issues. Fire programs located in areas that are not rife with Class I areas, PM_{10} non-attainment areas, or smoke-sensitive transportation corridors are commonly under voluntary smoke management programs and may be locally administered. These types of programs may be focused on concerns of local area impacts such as nuisance or transportation safety and can be well addressed through local level coordination among burners. State forestry agencies and their respective districts are frequently central points for dissemination of information; many examples of this type of program can be found in the southeastern states.

As air quality complexity rises with potential smoke impacts on non-attainment areas or Class I areas, legal requirements also rise, and frequently trigger a more centralized regulatory-based smoke management program. Attendant with the increased program requirements is the commensurate increased cost of the program. Direct costs of smoke management program administration are frequently recovered through the charging of fees to burners. Fees are frequently based on emissions production or tonnage of material to be consumed and are used to offset an authority's program administration costs. The increased indirect cost of frequent reporting requirements and other permitting tasks such as modeling of impacts and smoke management plan preparation are frequently overlooked. The most common centralized program approach is administered by the state or tribal air quality authority and can be found in such states as Colorado. States such as Florida and Oregon have opted to use their forestry agencies to help directly manage their smoke management programs. Oversight by the respective air quality regulatory authority is usually a part of such a program. There is an option for interagency approaches to smoke management program administration. This approach blends the lines between air quality regulatory agencies and land managers. Personnel from a land management agency may be out-stationed to the respective air quality regulatory authority to assist in the smoke management program administration. The states of Utah and Arizona use this approach respectively and have avoided program management fees in this fashion. This approach can also foster good inter-agency communication and development of joint air quality and land management objectives for smoke management programs.

The future of smoke management program administration will be a reflection of the implementation of the Regional Haze Rule (40 CFR Part 51), which creates a paradigm in which air quality impacts are viewed in a regional sense rather than by locality or state. Tribal smoke management programs are being rapidly developed and will help support this regional approach. The establishment of multi-state smoke management jurisdictions is rapidly becoming a reality with a joint effort by Idaho and Montana being a recent example. The $PM_{2.5}$ and ozone standards will also support this type of approach as the impacts of smoke are viewed as a long-range transport issue. The inclusion of all sources of fire emissions, such as agricultural burning and wildland burning, into a singular smoke management program is also a future direction in these programs, and can already be found in the Title 17 Rule in California.

Evaluation of Smoke Management Programs

Size of Program — In lieu of any other parameter that can describe the activity level of a burn program, the number of acres can be used to trigger level of effort for smoke management and subsequent evaluation of smoke effects. As mentioned elsewhere, the representation of fire activity in terms of emissions is more effective for air quality purposes. In lieu of emissions, fire size and fuel type can be used for triggering different smoke management requirements. Small burns located in remote areas with low emissions may not dictate any evaluation greater than tracking the activity level and date of burn. However, more complex situations such as a burn of several days' duration with heavy emissions located in the wildland/urban interface should be tracked more extensively for smoke management effectiveness. This same complex situation may track the effectiveness of emission reduction practices. It may be beneficial if the criteria are established in consultation with the local or state air regulatory agency. For federal agencies, these criteria can also be linked to the management plan's monitoring program. A post burn analysis of the smoke management plan and the burn's smoke effects can be extremely valuable to all concerned parties.

Intensity and Duration of Smoke Effects — The intensity and duration of smoke impacts are critical parameters that can represent a variety of smoke management effectiveness measures. Duration of smoke impacts upon the public, a non-attainment area, a transportation corridor or Class I area can be tracked and assessed through direct air quality monitoring.[2] The public can be tolerant of one day of heavy levels of smoke, however consecutive day impacts may lead to a rash of complaints. The criteria for evaluating a program may be to assess the number of consecutive days/hours of impact to a specific area. The intensity level of smoke impact also plays a role, as short bursts of high levels of smoke punctuated by clear air is frequently tolerable by receptors. An application of this type of criteria exists in Oregon where number and intensity of smoke intrusions is tracked annually. This type of criteria is applicable to individual incidents as well.

Methods of tracking the intensity and duration of smoke impact include:

- Number and type of public complaints (citizen, doctor, hospital, etc.);
- Intrusion of smoke into designated smoke sensitive areas through specific air quality measurement;
- Violations or percent increase of criteria pollutants attributable to smoke;
- Visibility impacts (local and regional).

As the National Ambient Air Quality Standards (NAAQS) include both short term and annual standards, the full impact of smoke on the NAAQS may not be readily determined until well after the burn season is completed, which further supports the importance of incorporating evaluation into a smoke management program. Impacts on visibility were previously viewed on an annual basis, however that has changed to tracking impacts on Class I areas to determine effects on the 20% clearest and 20% dirtiest days. These methods for tracking and evaluation should be established prior to the event or as part of the overall smoke management program as they can take significant planning or coordination. Pre-planning for the air quality element of the Wildland Fire Situation Analysis used by federal agencies for wildland fires

(USDI and USDA Forest Service 1998) can also be beneficial as the public, air quality regulatory community, and land management entity has the opportunity to increase acceptance of smoke effects.

The evaluation criteria should be as quantitative as possible in light of the complexity of the burn or program and the air quality concerns of the area. Proximity to non-attainment or Class I areas should automatically trigger some programmatic evaluation. Visibility should be considered in terms of plume blight, regional haze and impacts on safety (transportation). Conversely, a small incident with a small quantity or short duration of emissions in an area with few air quality concerns should not warrant extensive programmatic or individual incident evaluation effort. Again, advance coordination with concerned parties can help determine this varying level of effort.

If an incident or program results in a smoke intrusion above a pre-defined level such as number of complaints or presence of smoke in an avoidance area, the cause should be evaluated as soon as possible. The breakdown of the smoke management plan for an incident is equivalent to the breakdown of the fire behavior prescription for the burn. Smoke management contingency programs are another element of a smoke management program included in the Interim Policy (EPA 1998). Factors such as weather/smoke dispersion forecasting or fuel condition changes can lead to such a smoke intrusion and need to be evaluated quickly following a failure of the system in order to be addressed in a proactive fashion. Determination of what caused the adverse air quality impact allows for growth of the program through implementation of changes to avoid future recurrence. If a program or incident was conducted such that no smoke criteria were exceeded, evaluation of the factors which led to success are also valuable in building confidence among cooperating parties. The development of an annual report which outlines the air quality effects of a burning program or the smoke management program demonstrates the commitment to addressing both land management and air quality objectives and can show significant and useful trends to concerned parties. The knowledge that smoke impacts are being addressed effectively in terms of specific criteria is valuable when working with the concerned public and media.

Sources for Evaluation — Evaluation can be the assessment of air quality monitoring data collected by the land manager or utilization of existing air quality networks as operated by a regulatory agency (state/district/county/EPA/tribe). The meteorological conditions under which burns occur is another criteria that can be evaluated to help assess the smoke management program. For complex smoke areas, the use of digital camera points could allow distribution of the real-time images over the Internet to concerned parties, including the public. The concerned public can also be directly queried as to the level of smoke levels and duration of effects.

Annual Evaluation — One of the most effective means of evaluating the smoke management program is to hold periodic meetings amongst the concerned parties such as the burners, regulators and potentially-concerned public. The frequency of such reviews should depend on the air quality complexity and smoke impacts. Many statewide smoke management programs meet annually to review the years' activities, successes and problems. These meetings could include review of activity/emissions of burners, record-keeping efforts, effects tracked through the previously mentioned methods, and discussion of program logistics and costs. This same review meeting is also an opportune time to plan for future changes, discuss emerging issues, and conduct training if needed. The Interim Policy (EPA 1998) also urges such an evaluation process occur annually. These annual sessions may be an effective way of addressing an Interim Policy goal of assessing the adequacy of the rules and regulations pertaining to smoke management for a respective state, tribe or other managing entity. Reflecting the state of the smoke management program, whether statewide or at the land manager level, through the issuance of an annual program report on smoke management can be another technique for assessing the program and informing the public of the investment into smoke management.

Continuous Evaluation — If a specific incident were to have significant adverse effects, it might trigger immediate review to prevent a repeat occurrence. This immediate incident assessment can be an effective way of addressing pressing public concerns that may have arisen due to the impacts. During a wildland fire use incident, daily conference calls amongst the land manager and the regulatory agencies which discuss acres/fuels/emissions or qualitative smoke behavior can be very effective at addressing smoke concerns. This real-time evaluation can prevent conflict over smoke impacts and can ensure accurate information be provided to the public as well as incorporated into the message transmitted to the media by the respective agencies.

Incident debriefings should consider air quality effects and how they were addressed. In wildland fire use, there is a continuous evaluation of air quality as part of the Wildland Fire Situation Analysis (USDI and USDA Forest Service 1998). Establishment of criteria for evaluation of air quality effects prior to the actual event or implementation of a program can allow for greater buy-in by potentially affected parties when the fire occurs. Criteria for evaluation should also include indicators of success.

Literature Citations

Environmental Protection Agency. 1998. Interim air quality policy on wildland and prescribed fires. Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711. 39p.

40 CFR Part 51. Vol. 64 No. 126. Regional Haze Regulations – Final Rule. July 1, 1999.

USDI and USDA Forest Service. 1998. Wildland and prescribed fire management policy—implementation procedures reference guide. National Interagency Fire Center, Boise, ID. 81 pp. and appendices.

APPENDIX

Appendix A

Glossary of Fire and Smoke Management Terminology

The terms listed below were either taken from existing glossaries or developed specifically for this Guide. Where terms were taken from an existing glossary or document, the source reference is indexed in brackets (e.g. [source number]), with full reference citations provided at the end of the glossary. Note: Although the referenced definitions in this glossary were taken from other sources, the editors have revised or changed many of them from their original version.

Absorption coefficient	A measure of the ability of particles or gases to absorb photons; a number that is proportional to the number of photons removed from the sight path by absorption per unit length. (See Extinction coefficient). [2]
Activity fuel	Debris resulting from such human activities as road construction, logging, pruning, thinning, or brush cutting. It includes logs, chunks, bark, branches, litter, stumps, and broken understory trees or brush.
Activity level	Fuels resulting from, or altered by, forestry practices such as timber harvest or thinning, as opposed to naturally created fuels. [1]
Adiabatic lapse rate	Rate of decrease of temperature with increasing height of a rising air parcel without an exchange of heat at the parcel boundaries. (See Dry adiabatic lapse rate, Saturated adiabatic lapse rate, and Atmospheric stability).
Advection	The transfer of atmospheric properties by the horizontal movement of air, usually in reference to the transfer of warmer or cooler air, but may also refer to moisture. [1]
Aerial ignition	Ignition of fuels by dropping incendiary devices or materials from aircraft. [1]
Aerosol	A suspension of microscopic solid or liquid particles in a gaseous medium, such as smoke and fog. [2]

Air mass	An extensive body of air having similar properties of temperature and moisture. [1]
Air pollution	The general term referring to the undesirable concentration of substances (gases, liquids, or solid particles) to the atmosphere that are foreign to the natural atmosphere or are present in quantities exceeding natural concentrations. [1]
Air quality	The composition of air with respect to quantities of pollution therein; used most frequently in connection with "standards" of maximum acceptable pollutant concentrations. [1]
Allowable emissions	The emissions rate that represents a limit on the emissions that can occur from an emissions unit. This limit may be based on a federal, state, or local regulatory emission limit determined from state or local regulations and/or 40 Code of Federal Regulations (CFR) Parts 60, 61, and 63. [3]
Ambient air	Any unconfined portion of the atmosphere: open air, surrounding air. [4]
Ambient standards	Specific target threshold concentrations and exposure durations of pollutants based on criteria gauged to protect human health and the welfare of the environment. Ambient standards are not emissions limitations on sources, but usually result in such limits being placed on source operation as part of a control strategy to achieve or maintain an ambient standard. [3]
Anthropogenic	Produced by human activities. [2]
Area sources	A source category of air pollution that generally extends over a large area. Prescribed burning, field burning, home heating, and open burning are examples of area sources. [1]
Atmospheric inversion	(1) Departure from the usual increase or decrease with altitude of the value of an atmospheric property (in fire management usage, nearly always refers to an increase in temperature with increasing height). (2) The layer through which this departure occurs (also called inversion layer). The lowest altitude at which the departure is found is called the base of the inversion. (See Atmospheric stability; Temperature inversion; Mixing height; Mixing layer; Stable atmosphere; Unstable atmosphere; Subsidence inversion) [1]

Atmospheric pressure	The force exerted by the weight of the atmosphere, per unit area. At sea level the atmospheric pressure fluctuates around 1013 millibars (mb). At 5,000 feet (~1,500 m) above sea level the atmospheric pressure fluctuates around 850 mb. (See Standard atmosphere).
Atmospheric stability	The degree to which vertical motion in the atmosphere is enhanced or suppressed. (See Atmospheric inversion; Temperature inversion; Mixing height; Mixing layer; Stable atmosphere; Unstable atmosphere). [1]
Attainment Area	An area considered having air quality as good as or better than the National Ambient Air Quality Standards (NAAQS) as defined in the Clean Air Act. Note that an area may be in attainment for one or more pollutants but be a nonattainment area for one or more other pollutants. (See Non-attainment area). [3]
Avoidance	A smoke emission control strategy that considers meteorological conditions when scheduling prescribed fires in order to avoid incursions into smoke sensitive areas. [1]
Background level	In air pollution control, the concentration of air pollutants in a definite area during a fixed period of time prior to the starting up, or the stoppage, of a source of emission under control. In toxic substances monitoring, the average presence in the environment, originally referring to naturally occurring phenomena. [1]
Best Available Control Measures (BACM)	An emission limitation action based on the maximum degree of emission reduction (considering energy, environmental, and economic impacts) achievable through application of production processes and available methods, systems, and techniques. [4]
Burn severity	A qualitative assessment of the heat pulse directed toward the ground during a fire. Burn severity relates to soil heating, large fuel and duff consumption, consumption of the litter and organic layer beneath trees and isolated shrubs, and mortality of buried plant parts. [1]
Carbon dioxide (CO_2)	A colorless, odorless, nonpoisonous gas, which results from fuel combustion and is normally a part of the ambient air. [1]
Carbon monoxide (CO)	A colorless, odorless, poisonous gas produced by incomplete fuel combustion. Carbon monoxide is a criteria pollutant and is measured in parts per million. (See Criteria pollutants).

Carcinogen	Any substance that can cause or contribute to the production of cancer. [1]
Clean Air Act	A federal law enacted to ensure that air quality standards are attained and maintained. Initially passed by Congress in 1963, it has been amended several times. [1]
Combustion efficiency	The amount of products of incomplete combustion released relative to amounts produced from theoretically perfect combustion, expressed as a dimensionless percentage. Because perfect combustion produces only CO_2 and water, its combustion efficiency is 1.0. In combustion of wildland fuels, combustion efficiency can roughly range from as high as 0.95 (for flaming combustion) to as low as 0.65 (for smoldering combustion).
Condensation nuclei	The small nuclei or particles with which gaseous constituents in the atmosphere (e.g., water vapor) collide and adhere. [2]
Consumption	The amount of a specified fuel type or strata that is removed through the fire process, often expressed as a percentage of the preburn weight. [1]
Convection column	The rising column of gases, smoke, fly ash, particulates, and other debris produced by a fire. The column has a strong vertical component indicating that buoyant forces override the ambient surface wind. [1]
Convergence	The term for horizontal air currents merging together or approaching a single point, such as at the center of a low-pressure area producing a net inflow of air. The excess air is removed by rising air currents. Expansion of the rising air above a convergence zone results in cooling, which in turn often gives condensation (clouds) and sometimes precipitation. [1]
Criteria Pollutants	Pollutants deemed most harmful to public health and welfare and that can be monitored effectively. They include carbon monoxide (CO), lead (Pb), nitrogen oxides (NOx), sulfur dioxide (SO_2), Ozone (O_3), particulate matter (PM) of aerodynamic diameter less than or equal to 10 micrometers (PM_{10}) and particulate matter of aerodynamic diameter less than or equal to 2.5 micrometers ($PM_{2.5}$). [3]
Deciview	A unit of visibility proportional to the logarithm of the atmospheric extinction. (See Extinction coefficient; Visibility; Visual range). [2]

De minimis level	A level of emission or impact that is too small to be considered of concern. From the Latin phrase "de minimis non curat lex," meaning the law is not concerned with trifles.
Dew point	Temperature to which a specified parcel of air must cool, at constant pressure and water-vapor content, in order for saturation to occur. The dew point is always lower than the wet-bulb temperature, which is always lower than the dry-bulb temperature, except when the air is saturated and all three values are equal. Fog may form when temperature drops to equal the dew point. (See Dry-bulb temperature; Wet-bulb temperature). [1]
Dormant season burning	Prescribed burning conducted during the time of year when vegetation is not actively growing. In some parts of the country, dormant season burns are typically less intense than growing season burns.
Drift smoke	Smoke that has drifted from its point of origin and is no longer dominated by convective motion. May give false impression of a fire in the general area where the smoke has drifted. [1]
Dry adiabatic lapse rate (DALR)	Adiabatic cooling in a dry atmosphere. Usually about -5.5 degrees Fahrenheit per 1,000 feet (~-10 degrees centigrade per kilometer). (See Adiabatic lapse rate; Saturated adiabatic lapse rate).
Dry-bulb temperature	Originally, the temperature measured with a mercury thermometer whose bulb is dry. Commonly it is a measure of the atmospheric temperature without the influence of moisture. (See Wet-bulb temperature; Dew point).
Duff	The partially decomposed organic material above mineral soil that lies beneath the freshly fallen twigs, needles, and leaves and is often referred to as the F (fermentation) and H (humus) layers. Duff often consumes during the less efficient smoldering stage and has the potential to produce more than 50 percent of the smoke from a fire.
Ecosystem health	A condition where the parts and functions of an ecosystem are sustained over time and where the system's capacity for self- repair is maintained, allowing goals for uses, values, and services of the ecosystem to be met.

Ecosystem maintenance burn	A prescribed fire or wildland fire managed for resource benefits that is utilized to mimic the natural role of fire in an ecosystem that is currently in an ecologically functional and fire resilient condition. [5]
Ecosystem Processes	The actions or events that link organisms and their environment, such as predation, mutualism, successional development, nutrient cycling, carbon sequestration, primary productivity, and decay. Natural disturbance processes often occur with some periodicity
Ecosystem Restoration	The re-establishment of natural vegetation and ecological processes that may be accomplished through the reduction of unwanted and/or unnatural levels of biomass. Prescribed fires, wildland fires managed for resource benefits and mechanical treatments may be utilized to restore an ecosystem to an ecologically functional and fire resilient condition. [5]
Extinction coefficient	A measure of the ability of particles or gases to absorb and scatter photons from a beam of light; a number that is proportional to the number of photons removed from the sight path per unit length. (See Absorption coefficient; Deciview; Visibility; Visual range). [2]
Effective windspeed	The mid-flame windspeed adjusted for the effect of slope on fire spread. [1]
Emission factor (EFp)	The mass of particulate matter produced per unit mass of fuel consumed (pounds per ton, grams per kilogram). [1]
Emission inventory	A listing, by source, of the amount of air pollutants discharged into the atmosphere of a community. [3]
Emission rate	The amount of an emission produced per unit of time (lb./min or g/sec). [1]
Emission reduction	A strategy for controlling smoke from prescribed fires that minimizes the amount of smoke output per unit area treated. [1]
Emission Standards	A general type of standard that limit the mass of a pollutant that may be emitted by a source. The most straightforward emissions standard is a simple limitation on mass of pollutant per unit time (e.g., pounds of pollutant per hour). [3]

Extinction	The attenuation of light due to scattering and absorption as it passes through a medium. [2]
Federal Class I area	In 1977, Congress identified 156 national parks, wilderness areas, international parks and other areas that were to receive the most stringent protection from increases in air pollution. It also set a visibility goal for these areas to protect them from future human-caused haze, and to eliminate existing human-caused haze, and required reasonable progress toward that goal. [5]
Fine fuel moisture	The moisture content of fast-drying fuels that respond to changes in moisture within 1 hour or less; such as, grass, leaves, ferns, tree moss, pine needles, and small twigs (0-1/4" or 0.0-0.6 cm). (See Fuel moisture content; One-hour timelag fuels). [1]
Fire-adapted ecosystem	An ecosystem with the ability to survive and regenerate in a fire-prone environment.
Fire-dependent ecosystem	An ecosystem that cannot survive without periodic fire.
Fire exclusion	The policy and practice of eliminating fire from an area to the greatest extent possible, through suppression of wildland fires and a lack of fire use.
Fire regime	Periodicity and pattern of naturally occurring fires in a particular area or vegetative type, described in terms of frequency, biological severity, and area extent. [1]
Fire regime groups	Classes of fire regimes grouped by categories of frequency (expressed as mean fire return interval) and severity. Refers specifically to five groups used in Federal policy and planning: 0-35 years, low severity; 0-35 years, stand replacement; 35-100 years, mixed severity; 35-100 years, stand replacement; 200+ years, stand replacement. (See Fire return interval; Fire regime).
Fire return interval	Mean fire return interval. A mean, area-weighted time (in years) between successive fires for a respective area (i.e., the interval between two

	successive fire occurrences); the size of the area must be specified.
Fire severity	(See Burn severity.)
Fire use	The combination of wildland fire use and prescribed fire application to meet resource objectives. [6]
Fireline intensity	The rate of heat release per unit time per unit length of fire front. Numerically, it is the product of the heat yield, the quantity of fuel consumed in the fire front, and the rate of spread. [1]
Flaming combustion phase	Luminous oxidation of gases evolved from the rapid decomposition of fuel. This phase follows the pre-ignition phase and precedes the smoldering combustion phase, which has a much slower combustion rate. Water vapor, soot, and tar comprise the visible smoke. Relatively efficient combustion produces minimal soot and tar, resulting in white smoke; high moisture content also produces white smoke. (See Soot; Smoldering combustion phase). [1]
Forest floor material	Surface organic material, including duff, litter, moss, peat, down-dead woody pieces.
Forest residue	Accumulation in the forest of living or dead (mostly woody) material that is added to and rearranged by human activities such as harvest, cultural operations, and land clearing. (See Activity fuel). [1]
Fuel loading	The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area. This may be available fuel (consumable fuel) or total fuel and is usually dry weight. [1]
Fuel moisture content	The quantity of moisture in fuel expressed as a percentage of the weight; derived by weighing fuel sample both before and after thorough drying at (nominally) 212 degrees F (100 degrees C). (See Fine fuel moisture). [1]
Fuel reduction	Manipulation, including combustion, or removal of fuels to reduce the likelihood of ignition and/or to lessen potential damage and resistance to control. [1]
Fuel size class	A category used to describe the diameter of down dead woody fuels. Fuels within the same size class are assumed to have similar wetting and drying properties, and to preheat and ignite at similar rates during the combustion process. [1]

Fuel treatment	Manipulation or removal of fuels to reduce the likelihood of ignition and/or to lessen potential intensity, rate of spread, severity, damage, and resistance to control. Examples include lopping, chipping, crushing, piling and burning. [1]
Fuel type	An identifiable association of fuel elements of distinctive species, form, size, arrangement, or other characteristics that will cause a predictable rate of spread or resistance to control under specified weather conditions. [1]
Glowing combustion phase	Oxidation of solid fuel accompanied by incandescence. All volatiles have already been released and there is no visible smoke. This phase follows the smoldering combustion phase and continues until the temperature drops below the combustion threshold value, or until only non-combustible ash remains. (See Combustion; Flaming combustion phase; Smoldering combustion phase). [1]
Growing season burning	Prescribed burns conducted during the time of year when vegetation is actively growing, or when leaves have matured but not fallen.
Hazard reduction	Any treatment of living and dead fuels that reduces the threat of ignition and spread of fire. [1]
Haze	A sufficient concentration of atmospheric aerosols to be visible. The particles are so small that they cannot be seen individually, but are still effective in visual range restriction. (See Visual range; Extinction; Absorption coefficient; Regional haze). [2]
Heat release rate	(1) Total amount of heat produced per unit mass of fuel consumed per unit time. (2) Amount of heat released to the atmosphere from the convective-lift fire phase of a fire per unit time. [1]
Hydrocarbons	Compounds containing only hydrogen and carbon. [2]
IMPROVE	Interagency Monitoring of Protected Visual Environments. A cooperative visibility monitoring effort, using a common set of standards across the United States, between the EPA, Federal land management agencies, and state air agencies. [5]

Integrating nephelometer	An instrument that measures the amount of light scattered (scattering coefficient) and can be used to measure particulate matter concentrations from fires. [2]
Inversion	(See Atmospheric inversion) [2]
Isothermal layer	A layer of finite thickness in any medium in which the temperature remains constant.
Landscape	An area composed of interacting and inter-connected ecosystems that are repeated because of the geology, landform, soils, climate, biota, and human influences throughout the area. A landscape is composed of watersheds and smaller ecosystems.
Lead (Pb)	A criteria pollutant, elemental lead emitted by stationary and mobile sources can cause several types of developmental effects in children including anemia and neurobehavioral and metabolic disorders. Non-ferrous smelters and battery plants are the most significant contributors to atmospheric lead emissions. (See Criteria pollutants). [3]
Litter	The top layer of forest floor, composed of loose debris of dead sticks, branches, twigs, and recently fallen leaves or needles; little altered in structure by decomposition. (See Duff; Forest floor material). [1]
Mass fire	A fire resulting from many simultaneous ignitions that generates a high level of energy output. [1]
Mean fire interval	(See Fire return interval)
Micron	Micrometer (mm)—a unit of length equal to one millionth of a meter; the unit of measure for wavelength and also for the mean aerodynamic diameter of atmospheric aerosols. [2]
Mixing height	Measured from the surface upward, the height to which relatively vigorous mixing occurs in the atmosphere due to turbulence and diffusion. Also called mixing depth. [1]
Mixing layer	That portion of the atmosphere from the surface up to the mixing height. This is the layer of air within which pollutants are mixed by turbulence and diffusion. Also called mixed layer. (See Ventilation Index). [1]

Mopup	Extinguishing or removing burning material near control lines, felling snags, and trenching logs to prevent rolling after an area has burned, to reduce the chance of fire spreading beyond the control lines, or to reduce residual smoke. [1]
Mosaic	The central spatial characteristic of a landscape. The intermingling of plant communities and their successional stages, or of disturbance (especially fire), in such a manner as to give the impression of an interwoven, "patchy" design. [1]
National Ambient Air Quality Standards (NAAQS)	Maximum recommended concentrations of criteria pollutants to maintain reasonable standards of air quality. (See criteria pollutants). [3]
National Wildfire Coordinating Group (NWCG)	National interagency operational group authorized by the U.S. Secretaries of Agriculture and Interior and the National Association of State Foresters, designed to coordinate fire management programs of participating federal, state, local and private agencies to avoid wasteful duplication and provide a means of constructive cooperation.
Natural background condition	An estimate of the visibility conditions at each Federal Class I area that would exist in the absence of human-caused impairment. [5]
Nitrogen dioxide (NO_2)	The result of nitric oxide combining with oxygen in the atmosphere. A major component of photochemical smog. [1]
Nitrogen Oxide[s] (NO_x)	A class of compounds that are respiratory irritants and that react x with volatile organic compounds (VOCs) to form ozone (O_3). The primary combustion product of nitrogen is nitrogen dioxide (NO_2). However, several other nitrogen compounds are 2 usually emitted at the same time (nitric oxide [NO], nitrous oxide [NO], etc.), and these may or may not be distinguishable in available test data. [3]
Non-attainment area	An area identified by an air quality regulatory agency through ambient air monitoring (and designated by the Environmental Protection Agency), that presently exceeds federal ambient air standards. (See Attainment area). [1]
Nuisance smoke	The amount of smoke in the ambient air that interferes with a right or privilege common to members of the public, including the use or enjoyment of public or private resources.

One-hour timelag fuels	Fuels consisting of dead herbaceous plants and roundwood less than about one-fourth inch (6.4 mm) in diameter. Also included is the uppermost layer of needles or leaves on the forest floor. Fuel elements of this size usually respond to changes in moisture within one hour or less, hence the term 1-hr timelag. (See Fuel moisture content; Fine fuel moisture). [1]
One-hundred-hour timelag fuels	Dead fuels consisting of roundwood in the size range of 1 to 3 inches (2.5 to 7.6 cm) in diameter and very roughly the layer of litter extending from approximately three-fourths of an inch (1.9 cm) to 4 inches (10 cm) below the surface. Fuel elements of this size usually respond to changes in moisture within about one hundred hours or 3 to 5 days, hence the term 100-hr timelag. (See Fuel moisture content). [1]
One-thousand-hour timelag fuels	Dead fuels consisting of roundwood 38 inches in diameter and the layer of the forest floor more than about 4 inches below the surface. Fuel elements of this size usually respond to changes in moisture within about one thousand hours or 4 to 6 weeks, hence the term 1000-hr timelag. (See Fuel moisture content). [1]
Ozone (O_3)	A criteria pollutant, ozone is a colorless gas, ozone is the major component of smog. Ozone is not emitted directly into the air but is formed through complex chemical reactions between precursor emissions of volatile organic compounds (VOCs) and NO_X in the presence of sunlight. (See Criteria pollutants). [3]
Particulate matter	Any liquid or solid particle. “Total suspended particulates” as used in air quality are those particles suspended in or falling through the atmosphere. They generally range in size from 0.1 to 100 microns. [1]
Piling-and-burning	Piling slash resulting from logging or fuel management activities and subsequently burning the individual piles. [1]
PM_{10}	Particulate matter of mass median aerodynamic diameter (MMAD) less than or equal to 10 micrometers. A measure of small solid matter suspended in the atmosphere that can penetrate deeply into the lung where they can cause respiratory problems. Emissions of PM_{10} are significant from fugitive dust, power plants, commercial boilers, metallurgical industries, mineral industries, forest and residential fires, and motor vehicles. (See Criteria pollutants). [3]

$PM_{2.5}$	Particulate matter of mass median aerodynamic diameter (MMAD) less than or equal to 2.5 micrometers A measure of fine particles of particulate matter that come from fuel combustion, agricultural burning, woodstoves, etc. Often called respirable particles, as they are more efficient at penetrating lungs and causing damage. (See Criteria pollutants). [3]
Point sources	Large, stationary, identifiable sources of emissions that release pollutants into the atmosphere. Sources are often defined by state or local air regulatory agencies as point sources when they annually emit more than a specified amount of a given pollutant, and how state and local agencies define point sources can vary. [3]
Precursor emissions	Emissions from point or regional sources that transform into pollutants with varied chemical properties. [2]
Prescribed fire	Any fire ignited by management actions to meet specific objectives. A written, approved prescribed fire plan must exist, and NEPA requirements must be met, prior to ignition. This term replaces management ignited prescribed fire. [6]
Prescribed natural fire	Obsolete term. (See Wildland fire use) [6]
Prescription	A written statement defining the objectives to be attained as well as the conditions of temperature, humidity, wind direction and speed, fuel moisture, and soil moisture, under which a fire will be allowed to burn. A prescription is generally expressed as acceptable ranges of the prescription elements, and the limit of the geographic area to be covered. [1]
Prevention of Significant Deterioration (PSD)	A program identified by the Clean Air Act to prevent air quality and visibility degradation and to remedy existing visibility problems. Areas of the country are grouped into 3 classes that are allowed certain degrees of pollution depending on their uses. National Parks and Wilderness Areas meeting certain criteria are “Class I” or “clean area” in that they have the smallest allowable increment of degradation. [1]
Reasonably Available Control Measures (RACM)	Control measures developed by EPA that apply to residential wood combustion, fugitive dust, and prescribed and silvicultural burning in and around “moderate” PM10 nonattainment areas. RACM is designed to bring an area back into attainment and uses a smoke management program that relies on weather forecasts for burn/no-burn days.

	(See Best Available Control Measures [BACM]). [1]
Regional Haze	Visibility impairment caused by the cumulative air pollutant emissions from numerous sources over a wide geographic area. (See Haze).
Relative humidity (RH)	The ratio of the amount of moisture in the air, to the maximum amount of moisture that air would contain if it were saturated. [1]
Residual combustion phase	(See Smoldering combustion phase)
Residual smoke	Smoke produced by smoldering material. The flux of smoke originating well after the active flaming combustion period with little or no vertical buoyancy, and, therefore, most susceptible to subsidence inversions and down-valley flows. (See Nuisance smoke). [1]
"Right-to-burn" Law	A state law that provides liability protection for prescribed burners, providing they meet specified training and planning criteria. The degree of liability protection varies by state.
Saturated adiabatic lapse rate (SALR)	Adiabatic cooling in an atmosphere that is saturated with moisture. Usually about -3.0 degrees Fahrenheit per 1,000 feet (~-5.5 degrees centigrade per kilometer). (See Adiabatic lapse rate; Dry adiabatic lapse rate).
Scattering (light)	An interaction of a light wave with an object that causes the light to be redirected in its path. In elastic scattering, no energy is lost to the object. [2]
Secondary aerosols	Aerosol formed by the interaction of two or more gas molecules and/or primary aerosols. [2]
Slash	(see Activity fuel) [1]
Smoke concentration	The amount of combustion products (in micrograms per cubic meter) found in a specified volume of air. [1]
Smoke intrusion	Smoke from prescribed fire entering a designated area at unacceptable levels. [1]

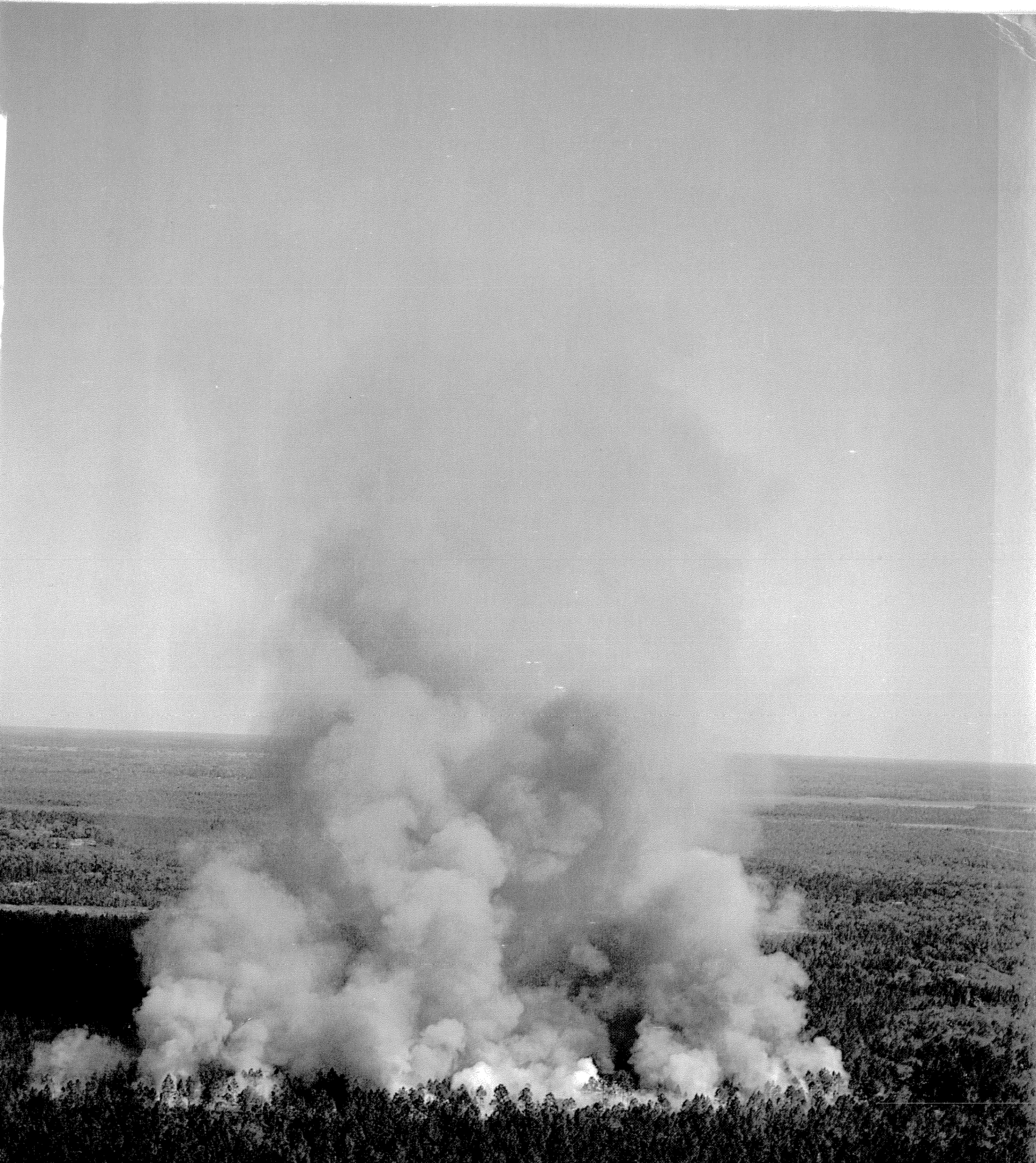
Smoke management	The policies and practices implemented by air and natural resource managers directed at minimizing the amount of smoke entering populated areas or impacting sensitive sites, avoiding significant deterioration of air quality and violations of National Ambient Air Quality Standards, and mitigating human-caused visibility impacts in Class I areas.
Smoke management program (SMP)	A standard framework of requirements and procedures for managing smoke from prescribed fires, typically developed by States or Tribes with cooperation from stakeholders.
Smoldering combustion phase	Combined processes of dehydration, pyrolysis, solid oxidation, and scattered flaming combustion and glowing combustion, which occur after the flaming combustion phase of a fire; often characterized by large amounts of smoke consisting mainly of tars. Emissions are at twice that of the flaming combustion phase. (See Combustion; Flaming combustion phase, Glowing combustion phase). [1]
Soot	Carbon dust formed by incomplete combustion. [4]
Stable atmosphere	A condition of the atmosphere in which vertical motion in the atmosphere is suppressed. Stability suppresses vertical motion and limits smoke dispersion. In a stable atmosphere the temperature of a rising parcel of air becomes cooler than its surroundings, causing it to sink back to the surface. Also called stable air. (See Atmospheric stability; Unstable atmosphere).
Standard atmosphere	A horizontal and time-averaged vertical structure of the atmosphere where standard atmospheric pressure at sea level is 1,013 mb, at 5,000 feet (~1,500 m) it is 850 mb, at 10,000 feet (~3,000 m) it is 700 mb, and the standard atmospheric pressure at 20,000 feet (~6,000 m) is 500 mb. Actual pressure is nearly always within about 30% of standard pressure. (See Atmospheric pressure).
State Implementation Plan (SIP)	Plans devised by states to carry out their responsibilities under the Clean Air Act. SIPs must be approved by the U.S. Environmental Protection Agency and include public review. Same as Tribal Implementation Plan (TIP). [5]
Subsidence inversion	An inversion caused by settling or sinking air from higher elevations. (See Atmospheric inversion; Temperature inversion).

Sulfur dioxide (SO_2)	A gas (SO_2) consisting of one sulfur and two oxygen atoms. Of interest because sulfur dioxide converts to an aerosol that is a very efficient at scattering light. Also, it can convert into acid droplets consisting primarily of sulfuric acid. (See Criteria pollutants). [2]
Sulfur oxides (SO)	A class of colorless, pungent gases that are respiratory irritants and precursors to acid rain. Sulfur oxides are emitted from various combustion or incineration sources, particularly from coal combustion. [3]
Temperature inversion	In meteorology, a departure from the normal decrease of temperature with increasing altitude such that the temperature is higher at a given height in the inversion layer than would be expected from the temperature below the layer. This warmer layer leads to increased stability and limited vertical mixing of air. [2]
Ten-hour timelag fuels	Dead fuels consisting of roundwood 1/4 to l-inch (0.6 to 2.5 cm) in diameter and, very roughly, the layer of litter extending from immediately below the surface to 3/4 inch (1.9 cm) below the surface. Fuel elements of this size usually respond to changes in moisture within about ten hours or less than a day, hence the term 10-hr timelag. (See Fuel moisture content). [1]
Total fuel	All plant material both living and dead that can burn in a worst-case situation. [1]
Tribal Implementation Plan (TIP)	Plans devised by tribal governments to carry out their responsibilities under the Clean Air Act. TIPs must be approved by the U.S. Environmental Protection Agency and include public review. Same as State Implementation Plan (SIP). [5]
Understory burn	A fire that consumes surface fuels but not overstory trees (in the case of forests or woodlands) and shrubs (in the case of shrublands).
Unstable atmosphere	A condition of the atmosphere in which vertical motion in the atmosphere is favored. Smoke dispersion is enhanced in an unstable atmosphere. Thunderstorms and active fire conditions are common in unstable atmospheric conditions. In an unstable atmosphere the temperature of a rising parcel of air remains warmer than its surroundings, allowing it to continue to rise. Also called unstable air. (See Atmospheric stability; Stable atmosphere).

Ventilation index	An index that describes the potential for smoke or other pollutants to ventilate away from its source. Also called clearing index. It is the product of mixing height and the mean wind within the mixed layer (trajectory wind).
Visual range	Maximum distance at which a given object can just be seen by an observer with normal vision. [1]
Volatile Organic Compounds (VOC)	Any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate that participates in atmospheric photochemical reactions. [3]
Wet-bulb temperature	Originally, the temperature measured with a mercury thermometer whose bulb is wrapped in a moist cloth. Commonly it is a measure of the atmospheric temperature after it has cooled by evaporating moisture. (See Dry-bulb temperature; Dew point).
Wildland Fire	Any non-structure fire, other than prescribed fire, that occurs in the wildland. This term encompasses fires previously called both wildfires and prescribed natural fires. [6]
Wildfire	An unwanted wildland fire. This term was only included [in the new Federal policy] to give continuing credence to the historic fire prevention products. This is NOT a separate type of fire under the new terminology. [6]
Wildland Fire Managed for Resource Objectives	(See Wildland Fire Use) [6]
Wildland Fire Use	The management of naturally ignited wildland fires to accomplish specific pre-stated resource management objectives in predefined geographic areas outlined in Fire Management Plans. Wildland fire use is not to be confused with "fire use," which is a broader term encompassing more than just wildland fires. [6]
Wildland Urban Interface (WUI)	The line, area, or zone, where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuel.

Literature Citations

1. National Wildfire Coordinating Group. 1996. Glossary of wildland fire terminology. PMS 205. Boise, ID: National Wildfire Coordinating Group, National Interagency Fire Center. 162 p.
2. Malm, William C. 1999. Introduction to visibility. Cooperative Institute for Research in the Atmosphere. NPS Visibility Program, Colorado State University, Fort Collins, CO: 79 p.
3. U.S. Environmental Protection Agency. 1999. Handbook for criteria pollutant inventory development: a beginner's guide for point and area sources. EPA-OAQPS-454-99-037. Research Triangle Park, NC. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards.
4. Terms of Environment. [online]. 1998. U.S. Environmental Protection Agency, Office of Communication, Education, and Public Affairs. Available: URL http://www.epa.gov/OCEPAterms/intro.htm [2001, Dec.].
5. Policy for categorizing fire emissions. [online]. 2001. Natural Background Task Team, Fire Emissions Joint Forum, Western Regional Air Partnership. Available: URL [2001, Nov.].
6. USDI and USDA Forest Service. 1998. Wildland and prescribed fire management policy-implementation procedures reference guide. National Interagency Fire Center, Boise, ID. 81 pp. and appendices.



SOUTHERN FORESTRY SMOKE MANAGEMENT GUIDEBOOK

DEDICATION

The staff of the Southern Forest Fire Laboratory respectfully dedicates this work to the memory of Robert W. Cooper whose guidance and inspiration long helped to bring science to the art of prescribed burning in the South.

HOW THIS BOOK WAS WRITTEN

Contributions from many scientists were required to complete this Guidebook. These contributors are listed as authors of the individual Chapters, and they take sole responsibility for technical content. Advice on overall content and applicability for users was provided by a group of compilers. The senior compiler worked directly with the authors to achieve a team product.

The compilers were:

SENIOR COMPILER

Hugh E. Mobley, Technical Specialist
Southeastern Area, State and Private Forestry
USDA Forest Service
Atlanta, Georgia

ASSOCIATE COMPILERS

Charles R. Barden, Executive Director
Texas Air Control Board
Austin, Texas

A. Bigler Crow, Professor of Forestry
Louisiana State University
Baton Rouge, Louisiana

Darwin E. Fender, Director of Land Management
International Paper Company
Mobile, Alabama

David M. Jay, Director
Division of Fire Management
Region 8, USDA Forest Service
Atlanta, Georgia

Ralph C. Winkworth, Director
Division of Forest Resources
Raleigh, North Carolina

Additional contributions in the form of technical reviews and assistance have helped to shape the final result. These are acknowledged in a Special Acknowledgments Section following the Glossary.

USDA Forest Service General Technical Report SE-10

December 1976

SOUTHERN FORESTRY SMOKE MANAGEMENT GUIDEBOOK

by

Southern Forest Fire Laboratory Personnel
Southeastern Forest Experiment Station

U.S. Department of Agriculture - Forest Service

Southeastern Forest Experiment Station

Asheville, North Carolina

and

Southern Forest Fire Laboratory

Macon, Georgia

ABSTRACT

A system for predicting and modifying smoke concentrations from prescription fires is introduced. While limited to particulate matter and the more typical southern fuels, the system is for both simple and complex applications. Forestry smoke constituents, variables affecting smoke production and dispersion, and new methods for estimating available fuel are presented.

KEYWORDS: Air quality, pollution, prescribed burning, smoke management, particulate matter, smoke concentrations, emission factors, components of forestry smoke, fuel loading.

TABLE OF CONTENTS

PERSPECTIVES

The air we breathe is essential to our lives and well-being. Forests are also important to our well-being. This Guidebook was prepared because the fires used in forest management can temporarily reduce air quality. Possible air quality impacts are discussed in detail, and ways are suggested to minimize unwanted atmospheric consequences when using fire in the forests. Procedures and suggestions to follow should be viewed as an opportunity to apply the best available knowledge, consistent with current need. In some locales, this need may be for use of only the more simple procedures. Complex air quality problems in other locales are likely to call for application of complex procedures. We have attempted to provide for both needs.

When compared with other sources of emissions, smoke from forestry burning has been regarded by regulatory agencies as only locally important. Its components are thought of as natural, occur from other sources as well, and may even be deemed inevitable if we accept prescribed fire as merely a practical substitute for wildfire. The ecological necessity for fire in some forests and the use of controlled fire to avoid the devastation of wildfires are strong arguments for its prescription. Forest pathologists recognize fire as a needed sanitation measure in some situations. On the other hand, because some smoke components are toxic, because they may interact unfavorably with one another and with other chemicals in the atmosphere, and because they can also impair safe or esthetic visibility, alternatives to open burning are sometimes strongly advocated. Also, burning forest fuels, like all carbonaceous fuels, produce traces of such implicated carcinogens as benzo(a)pyrene. Because not all health-related threshold levels have been established, a first reaction could be to avoid all open burning.

In truth, knowledge of interrelating synergistic effects and of general human susceptibility to airborne toxins is still too imperfect to suggest elimination of all smoke as attainable, or even necessary. And while heavy debate continues over *safe* or *no-effect* proposals, a seemingly rational control approach may emerge. Rather than attempt to regulate emissions merely on the basis of our rapidly improving detection (i.e., analytical) capability, it is suggested that acceptable levels for naturally occurring, physiologically active pollutants be related to their ambient (or background) levels.

This is not to say alternatives to open burning are not preferred when possible. Neither is it intended as anything but a strong message to apply a meaningful principle:

AVOID OVERLOADING NATURAL CLEARANCE MECHANISMS— BOTH PULMONARY AND ENVIRONMENTAL

By applying this principle, prolonged toxic contact and possibly increased physiologic effect on humans can be avoided. We believe that some smoke from forest management can be accepted in trade for benefits to the forest and for prevention of uncontrolled and overloading emissions from wildfire.

This Guidebook provides for the needs of both air and forest resource stewardship, and it is offered for local interpretation and use. It is offered, too, in the expectation that the health and well-being of the populace will be a primary concern of forestry smoke managers.

JOHN M. PIEROVICH
Program Manager
Southern Forest Fire Laboratory

CHAPTER I

SMOKE MANAGEMENT — WHAT IS IT?

by

Hugh E. Mobley, Technical Specialist
Southeastern Area — State and Private Forestry
USDA Forest Service
Macon, Georgia

PURPOSE OF THESE GUIDELINES

This Guidebook is designed to help you determine in advance:

WHAT YOUR FIRE WILL PUT INTO THE AIR
WHERE THIS MATERIAL WILL GO
WHAT WILL HAPPEN TO IT
WHAT EFFECT IT WILL HAVE
WHAT YOU CAN DO ABOUT IT

. . .and doing something about it to minimize environmental impact is *smoke management.*

Fire in the forest—natural, accidental, or deliberate—has been an important process in the ecology of the South for thousands of years, especially in the fire subclimax pine stands of the Coastal Plains. The use of prescribed fire to accomplish specific forest management objectives is now regarded as an indispensable tool of the forest manager (Mobley and others 1973). Today, nearly 3 million acres a year are burned by prescription in the Southern United States. In the past, the forest manager had only a minimum of information to help him determine what smoke from a prescription fire would do to visibility or to the atmosphere.

This Guidebook was developed for southern forest-land managers who prescribe fires, and for public agencies that are responsible for maintaining air quality in southern rural areas where forests are burned. What is presented is based upon the best available technology. Because knowledge is presently incomplete, the scope is limited to:

A broad breakdown of important southern fuels

Single prescription fires

Predictions of particulate matter emissions only.

A SOURCE OF MORE INFORMATION

As this Guidebook is being written, a parallel *Forestry Smoke Management Sourcebook* is also being developed. This Guidebook provides a great deal of information to practitioners in condensed form, while the *Sourcebook* will provide much additional information to key specialists. Any references made to the *Sourcebook* are intended to let you know that additional information is already available—at least in manuscript form. The first edition of the *Sourcebook* will probably be distributed in 1977 to regional and areal levels of the Forest Service and to State Foresters in a looseleaf format.

WHAT'S IN THIS GUIDEBOOK

A lot of information is presented for the first time in this Guidebook. Much is based on limited data and will be subject to updating. New information includes:

A system for estimating total fuel loading

A system for estimating available fuel

Particulate matter emission factors for major fuel types and burning techniques

A procedure for determining particulate matter production rate

A procedure for predicting smoke concentrations at any target area.

All are described in Chapters IV and V. This information is put together in a step-by-step decision-logic framework in Chapter VI that can be used to predict what smoke from a planned burn will do to the immediate airshed, and how it will affect visibility at any point downwind.

Although much more information can be found in the *Sourcebook* that is being developed, Chapter II summarizes what is presently known about the components of smoke plumes and their effects. Chapter III briefly reviews the Clean Air Acts and resulting Federal standards, State regulations that pertain to forestry burning, and a proposed method for determining a voluntary limit on emissions.

THERE ARE ALTERNATIVES

When land managers want to reduce competing vegetation or debris, they have various treatment alternatives: open burning, mechanical treatment, chemical application, close utilization, and doing nothing. No one system or type of treatment will meet *all* needs. The common treatments and considerations affecting their choices are summarized in table 1.

Three special categories of alternatives need further discussion: fire, utilization, and no treatment.

FIRE

Burning may be for more than one purpose; but because reasons vary by treatment, the discussions that follow are categorized by specific treatment objectives. In each of the following sections, a brief discussion of the need to meet the objective is also provided.

Reduction of Hazardous Fuels

Flammable vegetation and litter accumulate rapidly in pine forests. This material is fuel for wildfires, and excessive accumulation must be controlled to minimize losses and damages. When fire is prescribed to reduce hazardous fuel accumulations, the stand is virtually fireproofed for the next year or two. Fuel begins to accumulate immediately, but wildfires that do occur are of lower intensity and much easier to control; they burn less area and cause less damage to the forest. In the South, prescribed fire is used primarily for this purpose.

Figure 1. — Natural accumulations of understory vegetation are burned by prescription to reduce fire hazard.

Table 1.--Considerations in reducing forest debris by different treatments[1]

Considerations	Prescription burning	Chemicals	Forced-air burners
Adverse effect on air	Produces smoke	Chemical drift in foliar application	Very little visible emissions
Adverse effect on water	None[2]	May contaminate[3]	Negligible[2]
Adverse effect on soil	Negligible[2]	Negligible[2]	Some compaction[4]
Erosion	Possibly on steep slopes[5]	Negligible[2]	Possibly on steep slopes[4, 5]
Overstory	Negligible[2]	Negligible[2]	Skin trees[4]
Energy use	None	None to very little	Very high
Portability at site	Yes	Yes	None
Transportation requirements	Crew truck	Crew truck &/or tank truck Spray unit if used	Lowboy & tractor (2 units)
Costs[6]	20¢ to \$2.50/acre (avg. \$1) Site preparation up to \$6/acre	\$20 to \$45/acre (avg. \$25)	\$5 to \$10/ton of material treated
Effectiveness under stands	Effective	Effective on all sizes (live vegetation only)	Not effective
Effectiveness in the open	Effective only on small material	Not effective on dead material	Effective
Advantages	Inexpensive Fast Multiple benefits	Versatile Can treat any size material	Can handle large boles
Disadvantages	Air pollution Usable days are limited Not effective on large material	Public disapproval Regulated Possible offsite effects Volume not reduced Increased fire hazard	Need support equipment Costly Cannot treat understory
Best use	Hazardous fuel reduction Wildlife habitat improvement Grazing improvement	Timber stand improvement or conversion	Change in land use Site preparation Right-of-way clearing

continued

Table 1.--Considerations in reducing forest debris by different treatments[1] (continued)

Considerations	Drum choppers	Rotary-blade choppers	Dozing or shearing and root raking	Total-tree chippers
Adverse effect on air	Only exhaust emissions	Only exhaust emissions	Only exhaust emissions	Only exhaust emissions
Adverse effect on water	Negligible[2]	Negligible[2]	Sedimentation if on slope	Negligible[2]
Adverse effect on soil	Possible compaction	Some compaction	Compaction and removal of topsoil	Some compaction
Erosion	Moderate to steep slopes[5]	Possibly on steep slopes[5]	Very susceptible[5]	Possibly on steep slopes[4, 5]
Overstory	Skin tree boles & damage roots	None	Excessive damage	Skin trees[4]
Energy use	High	High	High	Very high
Portability at site	Limited in stands	Limited in stands	Limited in stands	None
Transportation requirements	Lowboy & tractor	Lowboy & tractor	Lowboy & tractor	Lowboy & tractor (2 units)
Costs[6]	\$30 to \$50/acre	\$10 to \$20/acre	\$50 to \$125/acre	About \$10/ton of material treated
Effectiveness under stands	Very limited Damage overstory	Limited	Cannot be used	Not effective
Effectiveness in the open	Effective	Effective on small material	Effective	Effective
Advantages	Effective in logging residue	Effective on small standing material Thorough treatment	Leaves ground clean	Salable product Can handle large boles
Disadvantages	Damages leave trees Blades tend to break on rocky ground	Limited where can be used	Debris left Erosion Costly Cannot treat understory	Need support equipment Initial investment Cannot treat understory
Best use	Site preparation	Maintenance of openings and rights-of-way	Change in land use Site preparation	Pulpwood logging Change in land use

[1]Adapted from Harrison (1975).
[2]Improper use could cause some adverse effects.
[3]If long-term chemicals are used or if treatment is close to stream or reservoir.
[4]Support equipment.
[5]These treatments are not feasible on steep slopes due to erosion and/or excessive cost--and generally not needed.
[6]Costs are usually higher in Piedmont areas.

Figure 2. — Wildlife favor the newly sprouting vegetation that appears after a prescribed burn.

Wildlife Habitat Improvement

As shrubs mature, the amount of food available to wildlife declines. Fires are often prescribed by wildlife biologists to improve wildlife habitat. Unpalatable brush and litter are removed, allowing production of palatable new plants and sprouts. Seeds and insects are also more plentiful on burned areas.

Site Preparation

Litter and debris must be removed to reduce competition and prepare a proper site for tree seeding or planting. Mechanical treatments alone may create large, unmanageable accumulations of debris that occupy space needed for growing trees. This debris can tie up nitrogen needed by the new stand for a prolonged period. Furthermore, mechanical treatment alone often fails to expose the soil properly. On the other hand, burning alone is not very effective either—except when the volume of debris is very low. Where the volume of logging debris is large, fire is often used in conjunction with mechanical treatment.

Figure 3. — Logging debris is burned by prescription to prepare sites for new crops of trees.

Control of Undesirable Species

In the absence of fire, most pine sites in the South tend to succeed to a climax type of scrub hardwoods. If these species are permitted to invade and compete with overstory pine, production is impaired and regeneration is very difficult.

Complete elimination of understory brush is not ecologically desirable or economically practical. It can be controlled with fire, however, if done while the understory is small. The resulting sprouts and growth of annuals provide good food and improved habitat for wildlife as well.

Disease Control

To control brownspot needle blight *(Scirrhia acicola* [Dearn.] Siggers) in longleaf pine *(Pinus palustris* Mill.) seedlings, the infected needles must be removed without damaging the bud. Fire is the only known practical way to properly remove the brownspot-infected needles of longleaf pines. Long experience with fire for this purpose has made it possible to do so without killing the bud.

Improve Forage for Grazing

Cattlemen produce beef on forested ranges. However, native grasses in the timber understory are smothered by shrubs and inferior hardwoods. Periodic, low-intensity fires control competition and maintain the grass species. In addition, the grass produced after such burning is especially nutritious and palatable for cattle.

Other Objectives

Other treatment objectives are to fireproof stands before initiating naval stores operations, to enhance esthetic appearance, and to improve accessibility for timber operators and hunters.

UTILIZATION

After allocating sufficient woody material to protect the soil from erosion, moisture loss, and unwanted loss of nutrients, most managers of commercial woodland would like to utilize all the remaining woody material for production of energy or as a raw material. Progress is being made in this

Figure 4. — Whole-tree chipping may be a practical alternative to burning in some places.

direction. In the South, merchantable pine trees are often utilized down to diameters of 2 to 4 inches. This is not usually the case, however, with hardwoods or forest areas being cleared for other uses.

One utilization system that looks promising is total-tree chipping. This system employs large, transportable chippers mounted on semitrailers. These will accept whole trees (limbs, leaves, and bark), cutting them into chips which can be blown into a truck and hauled to a pulpmill. No appreciable logging debris is left on areas logged in this manner. The investment cost and use of energy are high, but these disadvantages are offset where there is a market for such chips that contain bark and leaves. Some southern pulpmills can now accept substantial amounts of this type chipped material. Where such markets exist, total-tree chipping may be a better alternative than prescription burning. To meet energy needs, total-tree chippers can also be used to produce fuel for boilers. Studies and limited use are already underway.

Utilization of the small shrubs, brush, litter, and leaves within timber stands does not look promising. Volumes are too low and scattered to justify the cost of harvesting the material from among tree stems. Neither is there a developed market for most of this material. Pine needles can be sold for mulch when located close to metropolitan areas or nurseries.

NO TREATMENT

Choosing no treatment as an alternative—letting nature take its course—certainly has no immediate adverse effects on the quality of air, soil, or water. However, there can be other consequences:

Competition of unwanted plant species reduces timber growth.

Failure to prepare a site may make establishment of a new commercial timber stand difficult or impossible.

Wildlife habitat and food sources may disappear.

Palatable grass for cattle will be reduced or eliminated.

In stands of longleaf pine seedlings, mortality from brownspot disease will be increased.

Accessibility for hunting, timber management, and naval stores activites will be reduced.

Damage, as well as pollution of air and water, from wildfires will probably increase drastically—especially in areas of high fire occurence.

LITERATURE CITED

Mobley, Hugh E., Robert S. Jackson, William E. Balmer, and others

1973. A guide for prescribed fire in southern forests. Southeast. Area, State & Priv. For.-2, 40 p. USDA For. Serv., Southeast. Area, State & Priv. For., Atlanta, Ga.

Harrison, Robin T.

1975. Slash . . . equipment and methods for treatment and utilization. Equip. Dev. & Test Rep. 7120-7, 47p. USDA For. Serv. Equip. Dev. Center, San Dimas, Calif.

Figure 5. — Unless its growth is controlled in some manner, understory vegetation will take over desirable pine sites.

CHAPTER II

CONTENTS AND EFFECTS OF FOREST FIRE SMOKE

Charles D. Tangren, Physical Scientist
Charles K. McMahon, Research Chemist
Paul W. Ryan, Research Forester
Southern Forest Fire Laboratory
Southeastern Forest Experiment Station
USDA Forest Service
Macon, Georgia

The components of smoke are determined by the fuel and the process that converts this fuel to smoke. We therefore begin this Chapter with a description of the chemical elements of wood and the fuel. We then describe the process that first separates, and then recombines, these elements into the constituents of smoke. Although there are only a few major chemical elements in wood, the complex burning process results in numerous combinations and thereby generates a large number of chemical compounds.

We will then describe the products emitted from forest fires and their effects. Most investigators have measured only the major combustion products: carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (HC), and particulate matter. A few have measured nitrogen oxides (NO_X), organic acids, and aldehydes. The effects of forest fire smoke on man and his environment have not been measured directly. However, since the components of this smoke are similar to those of smoke from other combustion sources, we will draw information on effects from studies of individual components.

In the last section, we discuss particulate matter at some length. We provide detail on polycyclic organic matter (POM) and on physical characteristics. Size is perhaps the most important physical property of particulate matter. This size distribution is a good indicator of the potential for causing both health and visibility problems.

FUEL

The fuels of prescribed fires in the South, described in greater detail in Chapter IV, are mostly understory foliage, small branches, and the upper layers of ground litter. To a lesser extent, fuels also include the large branches and treetops left during land clearing and logging. Wildfires, which are often more intense than prescribed fires, may consume the foliage and small limbs of tree crowns, all litter layers, and organic soil. When burned, these fuel elements emit smoke with a chemical character that is basically determined by the chemical character of the fuel. Therefore, our discussion will start with an examination of the chemical character of forest vegetation.

CHEMICAL ELEMENTS OF WOOD

Chemical analysis of wood shows that it is composed of about 50 percent carbon, 6 percent hydrogen, 44 percent oxygen, and a fractional percent of what are called trace inorganic components. Surprisingly, there is only a minor difference in the major components between various wood species. The variability among trace components such as ash and nitrogen is greater. Ash content varies from 0.2 to over 0.9 percent for wood species in the United States. For nitrogen, the variation can be tenfold; for example, ponderosa pine *(Pinus ponderosa* Laws.) ranges from 0.13 percent nitrogen in boles to 1.04 percent nitrogen in growing needles.

More than half of the elements in the periodic table have been found in plants. At least 27 elements were identified in certain samples of white pine *(Pinus strobus* L.) wood and others doubtless occur in very small quantities.

Many of these elements are commonly recognized growth nutrients. Those occurring in fairly large quantities are called the major or macronutrients: nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. Elements required in smaller quantities are the minor or micronutrients: iron, manganese, zinc, copper, boron, and molybdenum. This list may be expanded further as more is learned about plants. Table 2 shows an example of the type and concentration of trace elements.

Table 2. — Relative amounts of various elements found in dried leaf tissue of healthy plants 1/

Element	Content	Content percentage
	Ppm	Percent
Nitrogen	20,000	2.0
Potassium	15,000	1.5
Calcium	15,000	1.5
Magnesium	3,000	0.3
Phosphorus	2,500	0.25
Sulfur	2,000	0.2
Iron	100	0.01
Boron	40	0.004
Manganese	40	0.004
Zinc	40	0.004
Copper	25	0.0025
Molybdenum	1	0.0001

1/ From Kramer and Kozlowski (1960).

Consideration of the trace components may seem trivial and unnecessary at first glance. Trace components, however, can cause major environmental problems. For example, the emission of sulfur oxides (regarded as a major pollutant) results from relatively minor amounts of sulfur in coal, oil, and other fossil fuels.

CHEMICAL COMPOUNDS IN WOOD

Ninety to ninety-five percent of the dry weight of wood is composed of three polymeric cell-wall constituents: cellulose, hemicellulose, and lignin. The other 5 to 10 percent includes constituents often listed as extractables or extraneous components. The extraneous components consist of several hundred individual chemical compounds that vary greatly between species, within species, and even within parts of the tree. In this group we find terpenes, tannins, resins, oils, pectins, gums, free organic acids, and minerals.

Wood contains between 41 and 53 percent cellulose. The composition of cellulose is quite uniform and independent of source; it consists of several hundred glucose-type carbohydrate units linked in a polymeric chain. Hemicellulose includes all noncellulosic polysaccharides such as the xylans, mannans, and glactans—plus related substances such as the uronic acids and their derivatives. No single, structural formula can be presented for this group; in fact, objections are often raised to the use of the collective term hemicellulose. The hemicellulose content of wood varies from 15 to 25 percent, depending on species. The lignin portion of wood is quite different chemically from cellulose and hemicellulose. It consists of polymeric, aromatic materials characterized by the presence of phenolic hydroxyl groups. Lignin includes a variety of substances that have similar chemical compositions, but may have structural differences. The basic building block of lignin is the phenyl propane unit. The lignin content varies from about 23 to 33 percent in softwoods, and from about 16 to 25 percent in hardwoods.

BURNING PROCESS

How the components of smoke are generated from burning forest vegetation is best understood by recognizing that fire is a two-stage process of pyrolysis and combustion. Although both stages occur simultaneously, pyrolysis occurs first; it is the initiating stage of chemical decomposition at elevated temperatures. It is most often viewed as a heat-absorbing (endothermic) reaction that converts large molecules into smaller ones. Fuel elements are separated into char, vapors, and high-molecular-weight hydrocarbons and particulate matter.

Combustion is the burning or rapid oxidation of the pyrolysate vapors escaping from the surface of the fuel. Defined in the most rigorous sense, combustion is a relatively fast, heat-releasing (exothermic), chemical reaction among pyrolysate vapors and oxygen.

Pyrosynthesis is a third activity that is a part of both the pyrolysis and combustion stages. It forms large and complex organic compounds from smaller free-radical hydrocarbons in the high-temperature and low-oxygen regions of the fuel and combustion zone. The formation of these compounds occurs in any combustion of carbonaceous fuel, and is due more to combustion characteristics than fuel characteristics.

Brown and Davis (1973), Browne (1963), and Murty Kanury (1972) have described what takes place during combustion of forest fuels. Combining their views, we can recognize three distinct phases of decomposition within fuel particles that are consumed. These phases—pre-ignition, flaming, and glowing—occur both sequentially and simultaneously in a moving fire front.

PRE-IGNITION PHASE (PYROLYSIS PREDOMINATING)

In this phase, the fuel is heated; volatile components move to the surface of the fuel and are expelled in the surrounding air. Initially, these volatiles contain large amounts of water vapor and some noncombustible organic compounds. As temperatures increase, hemicellulose, followed by cellulose and lignin, begin to decompose and release a stream of combustible organic products (pyrolysates). Because these gases and vapors are hot they rise, mix with the oxygen in the air, and ignite—producing the second phase.

FLAMING PHASE (GAS-PHASE OXIDATION PREDOMINATING)

In the second phase, the temperature rises rapidly from the heat of exothermic reactions. Pyrolysis continues, but it is now accompanied by rapid oxidation, or flaming, of the combustible gases being evolved in high concentrations. Carbon monoxide, methane, formaldehyde, organic acids, methanol, and other highly combustible hydrocarbon species are being fed into the flame zone. The products of the flame zone are predominantly carbon dioxide and water vapor. The water vapor here is not a result of dehydration as in the pre-ignition phase, but rather a major product of the oxidation of the fuel constituents.

Some of the pyrolyzed substances cool and condense without passing through the flame zone; others pass through the flames but only partially oxidize, producing a wide range of products. Many products of low molecular weight (methane, propane, etc.) remain as gases after cooling. Others, with higher molecular weights, cool and condense to form small, tarry, liquid droplets and solid soot particles as they move from the combustion zone. These condensing substances, along with the rapidly cooling water vapor that is being evolved in copious amounts, form the smoke that accompanies all forest fires.

Pyrosynthesis also occurs during this phase. Low-molecular-weight hydrocarbon radicals condense in the reducing region of the flames, leading to the synthesis of relatively large molecules such as the polynuclear aromatic hydrocarbons.

GLOWING PHASE (SOLID OXIDATION PREDOMINATING)

In the final phase of combustion, the exposed surface of the char left from the flaming phase is oxidized, producing a characteristic glow. This continues, as long as temperatures remain high enough, until only small amounts of noncombustible minerals remain as gray ash. Many times the arrangement of the burning material is such that temperatures cannot be maintained, and black char is left instead of gray ash.

Fuel particles are not always consumed in a moving fire front. Because of the size, condition, or arrangement of these particles, some are pyrolyzed but not oxidized and others are only partially consumed before the flame is extinguished. From the heat still available after the flaming phase, these particles emit large amounts of smoke. Still other particles continue in flaming combustion after the flaming phase has ended. As a result dehydration, pyrolysis, solid oxidation, and scattered flaming often occur simultaneously during this last phase. Where this condition exists, this last phase is called smoldering.

In subsequent Chapters, two fire phases are described: one with convective lift and one without. These phases are related to the activity of the convection column and not to the pre-ignition, flaming, glowing, and smoldering phases just described. In the convective-lift phase most emissions are entrained into a definite convection column. In the no-convective-lift phase, most emissions are not entrained into a definite convection column. The smoldering phase described in this Chapter occurs in both the convective-lift and no-convective-lift phases.

The discussion that follows covers the gases, vapors, and suspended particulate matter found in forestry smoke. Because of the special importance of particulate matter, a separate section will follow the more general discussions of primary and secondary emissions.

PRIMARY PRODUCTS

The burning of forest fuels emits hundreds, if not thousands, of chemical compounds into the atmosphere. An appreciation of the complexity of smoke can be obtained by a quick glance at research on the chemical characterization of tobacco smoke. As of 1968, over 10,000 publications had reported the identification of over 1,200 chemical compounds. To date, over 200 compounds have been identified in woods smoke.

Amounts of carbon dioxide and water vapor emitted are indicators of burning efficiency. The more efficient the combustion, the more CO_2 and water vapor produced. As combustion efficiency decreases, the proportion of undesirable emissions increases. Efficiency varies with the fuel moisture, fuel loading, type of fire (heading versus backing), and to a lesser extent, weather conditions. Perhaps the most dramatic finding to date is that heading fires produce approximately three times more particulate matter than backing fires. Wet fuels produce substantially more particulate matter than dry fuels.

Scientists have shown that amounts of emissions per ton of fuel consumed (emission factors) vary widely (table 3). In most cases, investigators pounds and the particles. Both temporary and lasting effects must be considered. The potential for a lasting effect is reduced by the detoxification capability of the body organs. Even compounds that can act synergistically to cause cell damage at levels below the threshold effect of each compound alone are a threat only in dosages above the body's capacity for detoxification.

Table 3. — Range of emission factors for components of forest fire smoke, with effect potentials

Components	Range of emission factors (pounds produced per ton of fuel consumed)	Effect potentials
Carbon dioxide	1/ 2,000-3,500	No direct
Water vapor	500-1,500	Visibility
Carbon monoxide	20-500	Health
Total suspended particulate matter	20-180	Visibility & health
Total hydrocarbons	10-40	Visibility & health 2/
Other organics	Unknown	Visibility & health 2/
Nitrogen oxides	1-9	Visibility & health 2/
Sulfur oxides	Negligible 3/	Health

1/ Values higher than 1 ton occur because of the chemical combination of carbonaceous constituents with oxygen in air to produce carbon dioxide.
2/ Includes effects from secondary photochemical products.
3/ A possible exception in the high-sulfur peat or "muck" soils.

measured only CO_2, CO, total hydrocarbons (HC), and particulate matter. In a very few instances they measured nitrogen oxides, aldehydes, and organic acids. Data on the latter groups are insufficient to estimate their emission factors with reasonable accuracy. Most studies have been limited to those emissions that are currently covered by the National Ambient Air Quality Standards.

In forest fires, the two products of complete oxidation—carbon dioxide (CO_2) and water vapor—make up over 90 percent of the mass emitted. The other 10 percent includes virtually all of the smoke and potential problem compounds. Products of major concern are carbon monoxide, particulate matter, gaseous hydrocarbons, other organic compounds, and the nitrogen oxides.

The effects of smoke from forest fires on man and his environment cannot yet be directly measured. We can only consider the potential effects of components known to exist in this smoke. The components that are potentially most harmful to humans are the volatile organic com-

CARBON DIOXIDE (CO_2)

Carbon dioxide is an odorless and colorless nontoxic gas formed abundantly in nature by the decomposition of organic substances. It is exhaled by man and animals during breathing and absorbed from the air by plants for use in photosynthesis. Its only potential as a pollutant is as a contributor to the overall greenhouse effect that may be causing a rise in the Earth's air temperatures.

WATER VAPOR (H_2O)

Water vapor is important because it can affect visibility near a fire, and because it interacts with the other combustion products to reduce combustion efficiency. It is theoretically possible to produce 1,720 pounds of water from a ton of fuel at a moisture content of 30 percent. Six hundred pounds are unbound, or free water, and 1,120 pounds are from the combustion reaction.

CARBON MONOXIDE (CO)

Carbon monoxide is a colorless and odorless toxic gas. Although concentrations of this gas can be quite high (100 to 200 ppm) right at the fireline, measurements on low-intensity prescribed fires show that normal atmospheric dilution processes are quite rapid—reducing this level to below 10 ppm approximately 100 feet downwind. Although the subject has been studied in depth and is still debated, reviews of the literature by Hueter and others (1972), Bartlett (1973), and Horvath (1973) indicate that the concentrations would probably have to exceed 10 ppm for a lengthy period to produce serious effects.

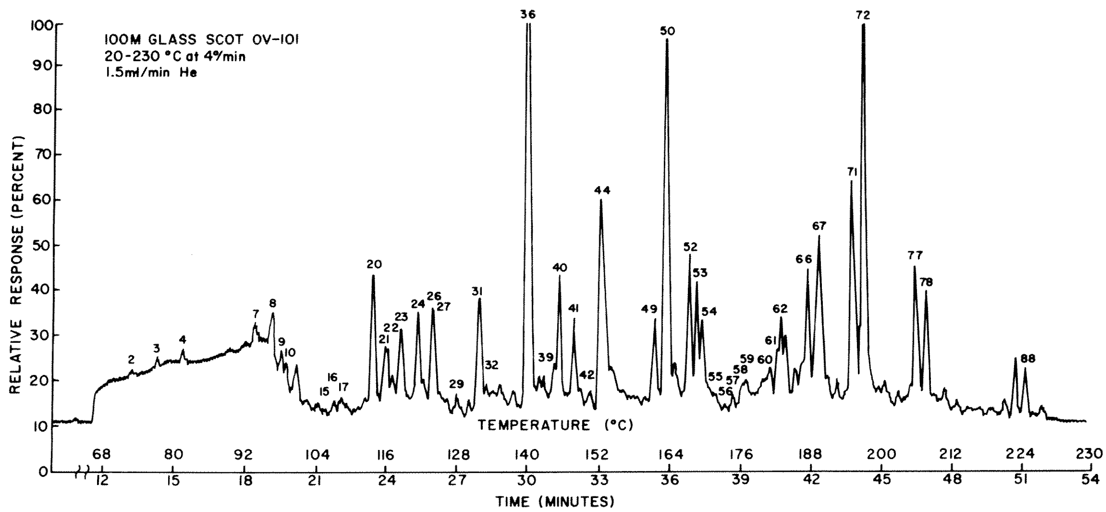
HYDROCARBONS (HC)

Hydrocarbons are organic compounds containing only carbon and hydrogen in the molecule. Two groups of hydrocarbons are particularly important potential pollutants: the low-molecular-weight olefins or unsaturated hydrocarbons and the high-molecular-weight, aromatic-type hydrocarbons. Methane, ethylene, and acetylene are the predominant low-molecular-weight hydrocarbons in forest fire smoke, comprising as much as 50 percent of the total. Lesser amounts of ethane, propane, propylene, methyl and ethyl acetylene, and butene and butane isomers have also been found. Characterization of the high-molecular-weight hydrocarbons to date is too fragmented and incomplete to draw any meaningful conclusions.

Hueter and others (1974) report that the hydrocarbons propylene, acetylene, and ethylene are known to affect plants. However, the amount of propylene in smoke is too small to be of direct concern, and both propylene and acetylene are considerably less phytotoxic than ethylene. Also, exposure from forest fire smoke is believed likely to be of too short a duration for any appreciable direct adverse effect from ethylene.

OTHER ORGANIC COMPOUNDS

In addition to the hydrocarbon organic compounds, there are literally hundreds of other organic gases and vapors in forest fire smoke. Figure 6 is a chromatogram of organic vapors



PEAK	COMPOUND
2	isopentane
2B	1-pentene
2C	furan
3	n-pentane
3A	isoprene
3B	acetone
4A	isopropanol
4B	cyclopentadiene
7	diacetyl
8	1-hexene
8A	methyl vinyl ketone
9	2-methylfuran
10	n-hexane
15	2,4-hexadiene
16	1,3,5-hexatriene
17	3-methylbutanal
20	benzene
21	cyclohexane
22	4-methylpentene
23	2,4-dimethylpentane
24	1-trans-2-dimethyl-cyclopentane

PEAK	COMPOUND
24A	sorbaldehyde (tent.)
26	2,5-dimethylfuran
26A	n-heptane
27	cis-2-heptane
29	2-vinylfuran
31	2,3-dimethyl-2-pentane
32	2,4-dimethylhexane
36	toluene
39	1-octene
40	2,3-dimethylhexa-1,4-diene
41	n-octane
42	2,3,5-trimethylfuran
44	furfural
49	ethyl benzene
50	p-xylene
50A	2-propionylfuran (tent.)
52	styrene
53	o-xylene

PEAK	COMPOUND
54	n-nonane
54A	2-isopropylfuran
55	anisole
56	2-methyl-5-isopropenylfuran
57	cumene
58	n-decane
59	camphene (tent.)
60	n-propylbenzene
61	m-ethyltoluene
62	p-ethyltoluene
66	1-decene
67	benzofuran
71	m-diethylbenzene
72	limonene
77	p-α-dimethylstyrene
78	n-undecane
88	n-dodecane

Figure 6. — Chromatogram of organic vapors in loblolly pine smoke. Each peak represents a separate compound.

sampled from a laboratory fire of loblolly pine *(Pinus taeda* L.) needles. Each peak represents a separate compound. This display includes only some of the organic compounds in smoke—principally those with 4 to 12 carbon atoms. Included in this fraction are many oxygenated compounds—mostly organic acids, aldehydes, and furans—plus many high-molecular-weight aliphatic and aromatic hydrocarbons. Several low-molecular-weight and oxygenated species, especially the carboxylic acids (formic and acetic acids, etc.) and the reactive aldehydes (formaldehyde, acetaldehyde, acrolein, etc.) have been reported as minor, but significant, constituents of woods smoke.

In extensive reviews of the health effects of volatile organic compounds, Balchum (1973) and Hueter and others (1974) point to the lower molecular-weight and more soluble aldehydes—such as formaldehyde—as irritants to the mucous membranes of the eyes and upper respiratory tract. Formaldehyde irritates the eyes, nose, and throat at levels of 0.01 to 1.0 ppm, causes discomfort at 2.0 to 3.0 ppm, and can only be tolerated for 10 to 30 minutes at 4.0 to 5.0 ppm. The higher molecular-weight and less soluble aldehydes are deep-lung irritants.

Balchum (1973) and Hueter and others (1974) have found that the unsaturated aldehydes are several times more irritating and toxic than the saturated aliphatic aldehydes. Within the saturated and unsaturated aldehydes, toxicity increases with decreasing molecular weight. For example, unsaturated acrolein can cause moderate irritation of the eyes and nose within 5 minutes at levels as low as 0.25 ppm and becomes intolerable at 5.0 ppm within this same time. In contrast, saturated acetaldehyde does not become an irritant until it reaches a concentration of 50 ppm, far above anticipated levels.

OXIDES OF NITROGEN (NO_x)

Oxides of nitrogen (NO_x) include both nitric oxide (NO) and nitrogen oxide (NO_2). NO is a colorless gas that, in contact with air, forms NO_2, a reddish-brown gas. The normal mechanism for the formation of oxides of nitrogen in combustion is through fixation of atmospheric nitrogen and oxygen in the burning zone, principally at temperatures above 1,600° C. This is above temperatures normally occurring in prescribed forest fires. However, these temperatures could be achieved in piled slash or wildfires.

Nitric oxide can also be formed at lower temperatures in the presence of hydrocarbon-free radicals (Ay and Sichel 1976). Significant amounts of nitric oxide may be formed in this way in forest fires. Nitrogenous compounds in forest fuels are another potential source of oxides of nitrogen in emissions. Information on nitrogen oxide emission rates from forest fires is scanty and inconclusive.

NO_2 is about four times more toxic than NO and exerts its primary effect on the lungs. However, based on the reviews of Hueter and others (1973) and Shy (1973), concentrations far exceeding those expected of a forest fire are required for direct effects on man. The real importance is in the formation of a whole train of secondary products.

SULFUR OXIDES (SO_x)

Sulfur oxides are probably produced only in negligible quantities because most forest fuels contain less than 0.2 percent sulfur. Sulfur oxides have not yet been detected in forest fire smoke. A notable exception is certain organic soils in Florida which have a sulfur content of about 4 percent and are under current investigation.

SECONDARY PRODUCTS

We have briefly reviewed the major findings on primary or fire-produced emissions and their effects. As smoke plumes travel through the atmosphere, secondary products can be generated through mixing of primary effluents or photochemical activity. Evans and others (1974), for example, reported formation of ozone in the upper layer of a smoke plume when it was irradiated with sunlight. Some secondary products are more harmful than the primary products, and some are harmless.

Health effects due to the interaction of particulate matter and sulfur dioxide have been found in numerous air pollution studies (Engel and others 1971, National Academy of Sciences 1973 and 1975). Our current studies, while only yielding tentative results, tend to confirm that these and other secondary reactions will take place.

PARTICULATE MATTER

In this Guidebook, particulate matter is defined as any dispersed aggregate matter, solid or liquid (other than water), that for practical purposes is larger than about 0.002 micron in diameter, but smaller than 500 microns in diameter. The size, shape, porosity, density, and other physical properties of particulate matter are highly variable. Aerosol, another often-used term, is considered here to mean small, airborne particulate matter.

Particulate matter remains suspended in the atmosphere for periods of a few seconds to several months. Suspended particulate matter is that portion which, because of its small size (below 5 to 10 microns in diameter), is transported long distances in the atmosphere and has the greatest potential for environmental impact. Suspended particles are of greatest concern in smoke management.

The most obvious environmental effect of smoke from prescribed forest fires is a reduction in visibility. This effect is caused by the particles that absorb and scatter light, washing out the contrast that exists between the source and its background. These particles can also scatter the sunlight that illuminates the air between the source and the receiver, again washing out the contrast as distance increases. This temporary reduction in visibility can hinder safe operation of aircraft and automobiles or the enjoyment of scenic vistas.

The soiling ability of larger carbon-type particles is another environmental effect of forest fires; but in prescription burning, these particles tend to fall out of the smoke column close to the fire rather than adding to the general pollution level.

Figure 7. — A reduction in visibility is the most obvious adverse effect of smoke on the environment.

A term that is increasing in popularity and significance is fine particulate matter (or sometimes, respirable suspended particulate [RSP]) which comprises particles below 2 to 3 microns. These have an especially long residence time in the atmosphere, contribute to smog formation, and penetrate deeply into the lungs. Also, they may act synergistically with gases or other particles.

According to the review of Engel and others (1971), particulate matter may contribute to accelerated corrosion of metals upon which they are deposited by sorbing corrosive chemicals from the atmosphere. Almost all of this information comes from studies of urban versus rural areas where gaseous pollutants in the urban areas are adding to the corrosion.

Health effects of particulate matter are determined by three properties: size, sorption, and chemical composition. Sizes of particles are important because of their relation to different parts of the respiratory system. The three main parts of the respiratory system are the nasopharyngeal, tracheobronchial, and pulmonary. Of these, the upper two contain cellular tissue with hairlike outgrowths (cilia) covered with mucus, and the lower one contains moist cellular tissue covered by a surface-active material to prevent the collapse of the air sacs at the end of respiration. Through inertial impaction and gravitational settling, the larger particles are deposited in the upper two parts of the system and then expelled. As the size decreases below 5.0 microns in diameter, increasing numbers are deposited in the lower respiratory tract—including over 50 percent of those between 0.01 and 0.1 micron that penetrate this far. Many forest fire smoke particles, as shown in the physical properties subsection, have a potential for being deposited deep in the lungs.

Sorptive properties of particles make them potential carriers of toxic material. In a review of the effects of particles on health, Engel and others (1971) found that formaldehyde, which does not itself readily penetrate the upper respiratory tract, is carried to the lungs by adsorption to small particles—causing increased toxic effect. In their review of hydrocarbons, Hueter and others (1974) found that the toxicity of acrolein and formaldehyde (both constituents of forestry smoke), when in the presence of certain inert aerosols, appeared more toxic to mice.

Particulate matter can consist of just a few easily analyzed solid inorganic compounds as in some industrial smoke, or it can consist of several hundred liquid and solid compounds in a complex organic/inorganic matrix as in certain natural aerosols. Examples of natural particulate matter are: (1) the coarse, inorganic mineral dust particles derived from windblown soil, (2) the inorganic sea-salt particles emitted from the oceans, (3) the powderlike, organic pollens from plants, and (4) the organic aerosols produced by forest fires.

Solvent extractions with benzene have traditionally been used to estimate the amount of organic compounds in particulate matter. The benzene soluble organic (BSO) fraction of particulate matter from fires in various southern fuels has been found to range from 40 to 75 percent. Some of this variation is due to the type of fire. In comparison, the average BSO fraction of ambient air particulate matter is about 8 percent.

The BSO percentage, while a measure of the organic content of particles, gives no information about the individual organic compounds. Very little of the chemical analysis required for this has been accomplished for forest fire particles. However, a considerable amount of analysis of the smoke in flavoring food, from tobacco, and from burning building materials has been completed. Those analyses that covered the burning of cellulose, hemicellulose, and lignin have identified several hundred organic compounds in the particulate matter. These compounds, expected to be a part of forest fire smoke, are categorized in the general classes: organic acids, alcohols, aldehydes, furans, ketones, and aromatic compounds. The aromatic compounds include the esters, phenols, and polycyclic organic matter.

POLYCYCLIC ORGANIC MATTER

Polycyclic organic matter (POM) is of special interest in smoke management because it is a class of compounds containing many physiologically active substances. Benzo(a)pyrene (BaP) and other implicated carcinogens are usually found in POM.

POM is formed by the pyrosynthesis of small carbon fragments into large hydrocarbon molecules in the low-oxygen region of combustion processes. It is found in virtually all burning which involves carbonaceous fuels. Production of POM is more dependent on the conditions of the fire than the type of carbonaceous fuel. For example, inefficient, residential coal furnaces produce substantially more benzo(a)pyrene per unit of fuel consumed than do more efficient coal furnaces in power plants (National Academy of Sciences 1972).

In recent laboratory experiments, BaP concentrations were measured in the smoke from burning slash pine (*Pinus elliottii* Engelm.) needles. With the laboratory burning tray on a slope of 50 percent, heading and backing fires (two replicates) were set at three loadings (pounds per square foot) each.

Heading fires, as expected, usually produced more particulate matter per ton of fuel at a given fuel loading (table 4). Backing fires, however, produced substantially more benzo(a)pyrene, especially at light loadings.

Within heading fires, the smoldering phase produces higher amounts of both BaP and particulate matter than the corresponding flaming phase (table 5).

The differences in BaP production can be explained partly by the conditions required for its formation—moderately high temperatures, low oxygen, and long residence times in the reaction zone. Carbon fragments in the slow-moving, backing fires (especially the light loadings) remained under these optimum formation conditions substantially longer than in the heading fires. Within heading fires the carbon fragments in the

Table 4. — Benzo(a) pyrene (BaP) and total suspended particulate matter (TSP) from burning pine needles 1/

Type of fire and fuel loading (pounds per square foot)	Emissions	
	Benzo(a)pyrene	Total suspended particulate matter
	ng/g 2/	Pounds per ton 3/
Backing:		
Light (0.1)	3,500	22
Medium (0.3)	560	8
Heavy (0.5)	240	5
Heading:		
Light (0.1)	38	22
Medium (0.3)	40	88
Heavy (0.5)	100	129

1/ Fuel moisture content for all fires ranged from 18 to 27 percent.

2/ Nanograms of benzo(a)pyrene per gram of fuel burned. A nanogram is 0.000000001 gram.

3/ Pounds of total suspended particulate matter per ton of fuel burned.

smoldering phase, even though at less than optimum BaP formation temperatures, are subject to these conditions for substantially longer periods than in the corresponding flaming phase.

The benzo(a)pyrene levels shown in tables 4 and 5 are generally in the ranges reported elsewhere for open burning of landscape refuse, grass clippings, leaves and branches (National Academy of Sciences 1972), and hardwood leaves (Jones 1975). The one exception is the value we observed for lightly loaded backing fires. That value is about 10 times what we might have expected from reading earlier study results.

Table 5. — Benzo(a)pyrene (BaP) and total suspended particulate matter (TSP) from flaming and smoldering phases of burning pine needles 1/

Fire phase and fuel loading (pounds per square foot)	Emissions	
	Benzo(a)pyrene	Total suspended particulate matter
	ng/g 2/	Pounds per ton 3/
Flaming:		
Light (0.1)	33	14
Medium (0.3)	17	17
Heavy (0.5)	36	40
Smoldering:		
Light (0.1)	100	59
Medium (0.3)	55	143
Heavy (0.5)	140	192

1/ Fuel moisture content for all fires ranged from 18 to 27 percent.
2/ Nanograms of benzo(a)pyrene per gram of fuel burned. A nanogram is 0.000000001 gram.
3/ Pounds of total suspended particulate matter per ton of fuel burned.

General conclusions about benzo(a)pyrene in forestry smoke cannot be drawn at this time. The levels we found in our limited number of laboratory fires were very low to moderate. Our data may indicate, however, that one should be cautious in declaring backing fires to be the cleanest. It is true that backing fires can be expected to produce a lower volume of all particulate matter than heading fires. But, it appears that some backing fires can be expected to produce more BaP than heading fires.

PHYSICAL PROPERTIES

The particulate fraction of forest fire smoke is highly variable. As we have shown, this high variability is not only in the mass produced but also in the size, shape, porosity, density, and other physical properties of individual particles. Particles are responsible for two major smoke problems: respiratory effects and visibility reduction. Respiratory effects have been discussed previously.

Visibility reduction is caused by the scattering of light by the particles. All particles do not scatter light to the same degree. Those having diameters within the wavelength of visible light, between 0.3 and 0.8 micron, cause the maximum scattering. Unfortunately, these sizes of particles remain suspended in the air the longest.

Particle Formation

The majority of particles in forest fire smoke are formed from the gaseous organic compounds produced by pyrolysis and combustion. Nucleation, condensation, and coagulation form both liquid and solid particles ranging upward in size from about 0.002 micron. From 60 to 70 percent of the total particles produced are liquid. These are formed into a spherical shape by the condensation of organic vapors and range from the highly volatile and short lived to the long lived, tarry, and viscous. Figure 8 is a photomicrograph that shows both the spherical liquid particles and the irregular solid particles.

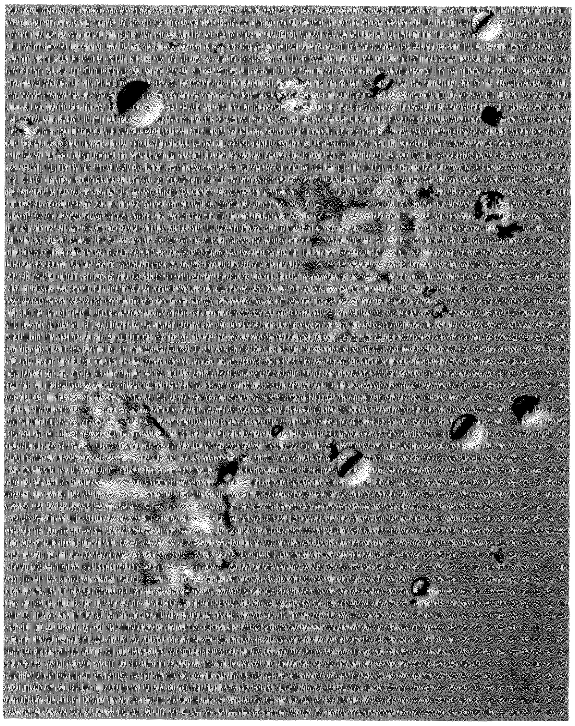


Figure 8. — Liquid particles are spherical, whereas solid particles are irregularly shaped. Characterizing particle shapes often helps in evaluating environmental effects.

Solid particles created by the combustion process, particularly the smaller ones, can also assume a spherical shape. More commonly, however, they assume other forms that approximate flattened discs, angular cubes, and long, chainlike agglomerates. Sizes of the solid particles range from 0.01 micron to 5 microns in diameter. Frequently, the small particles will bind together to produce larger agglomerates that vary in shape from roughly circular to long, slender, chainlike masses. Figure 9 is a scanning electron micrograph illustrating these agglomerated particles.

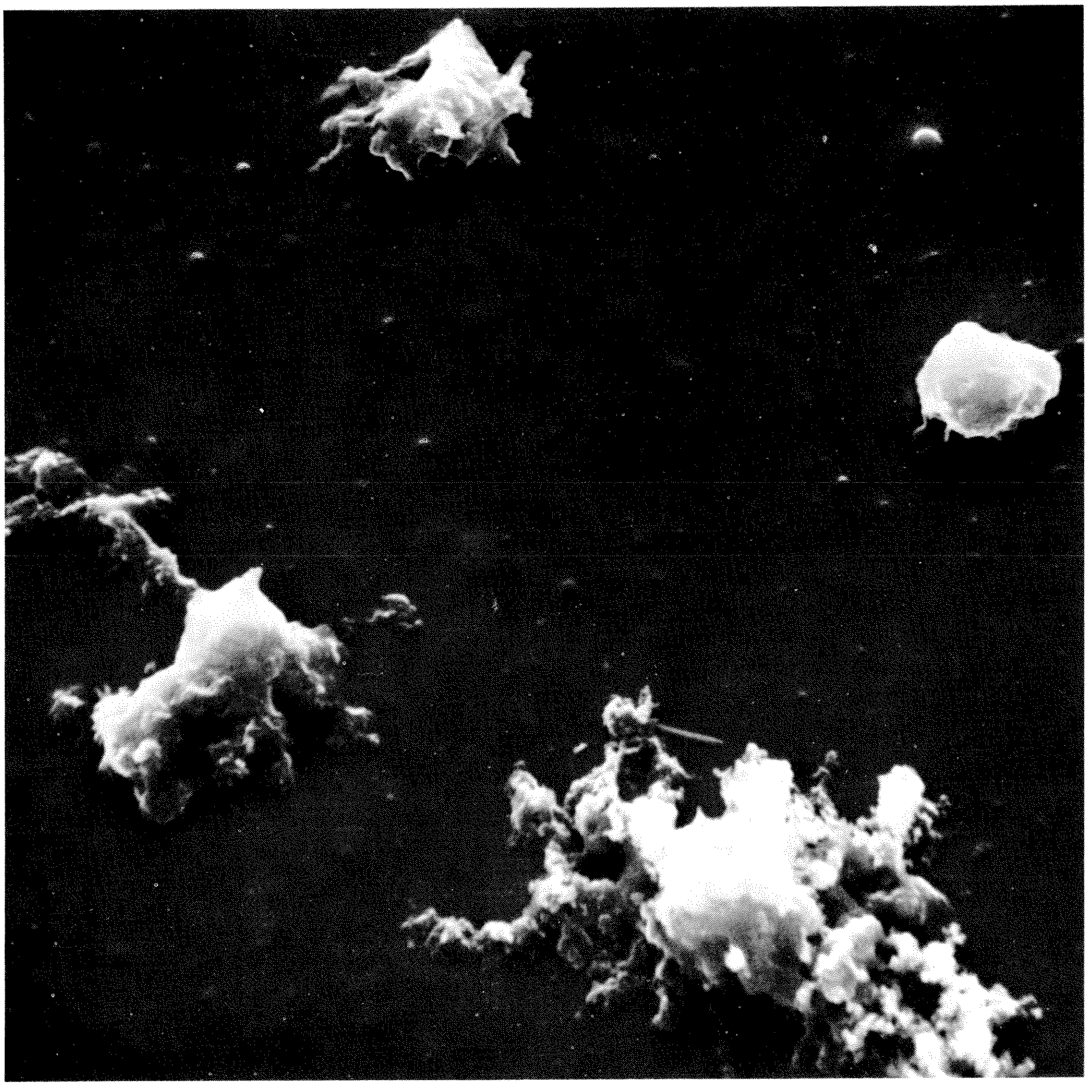


Figure 9. — A scanning electron micrograph shows angular nature of solid primary particles and the aggregation of small particles into long, chainlike masses.

Particles are also formed by the mechanical action of turbulent forces present in the fire zone. These forces simply break up the fire-weakened fuel and lift small pieces into the heated air column over the fire. Initially, mechanically formed particles are fewer in number but usually are larger and have more mass than the chemically produced ones. Figure 10 shows this type of particle.

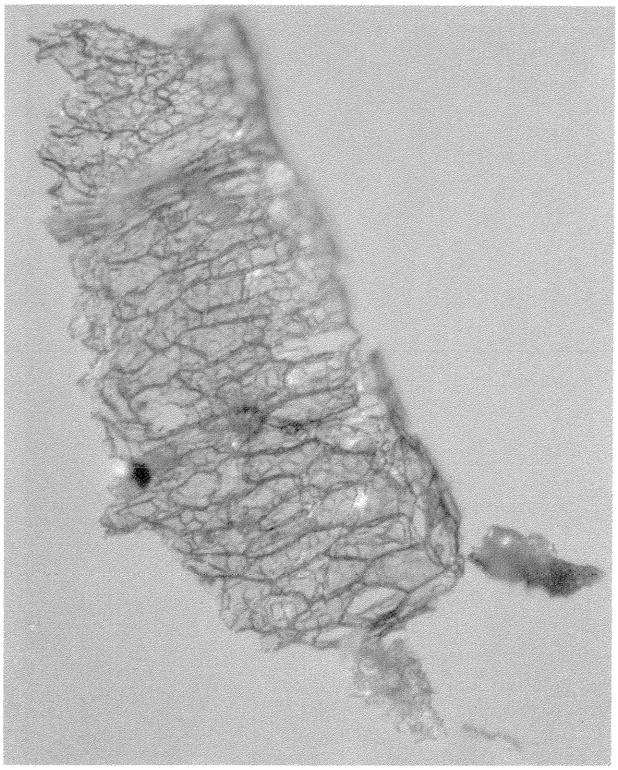


Figure 10. — A large, mechanically formed particle. Notice that plant structures can still be identified.

Mass Distribution

Particles are produced in a wide range of sizes. The amount of particulate matter in each size category is called the size distribution, which can be expressed as mass or number of particles. We report both mass and number distributions because some effects are more closely related to mass distribution and others to number distribution. In addition, no existing instrument can measure the full range of sizes. Expensive instruments are available to measure very small particles; they usually record number distributions. Commonly available instruments for measuring larger particles usually record mass distributions.

A particle's mass, in combination with its size and shape, determines its aerodynamic size. Aerodynamic size equates an irregular shape to a sphere and can be much different than physical size. The solid and liquid particles in figure 8, although of obviously different physical sizes, are the same aerodynamic size. Aerodynamic size is more closely related to particulate matter dispersion and respiratory effects, while physical size is more related to visibility effects.

We sampled the aerodynamic mass size distribution of particulate matter from several experimental backing fires in slash pine and palmetto-gallberry fuels of Georgia and Florida. About 70 percent of the particle mass from the slash pine fires was less than 0.4 micron in diameter, and 95 percent was less than 1 micron. Similar results have been reported from other studies in the United States and elsewhere. In the smoke from Douglas-fir *(Pseudotsuga menziesii* [Mirb.] Franco) fires in the Northwest, 69 percent of the particle mass was found to be less than 0.3 micron and 82 percent less than 1 micron (Sandberg and Martin 1975). Additional information collected with a scanning electron microscope showed that most single, spherical particles were about 0.1 micron in diameter. Particulate matter in the smoke from burning rice residue was found to have mass median diameters that range from 0.1 to 0.3 micron (Goss and Miller 1973). Reports from Australia and England show that woods smoke particles are about 0.1 micron in diameter (MacArthur 1966 and Foster 1960).

Number Distribution

A recently developed instrument has given us the opportunity to measure the lower range of particle distribution. It was used in field experiments during the 1974-75 fire season. These distributions (fig. 11) are from fires in longleaf-slash pine needles in Louisiana, a sawgrass stand in the Everglades of Florida, light brush under a loblolly pine stand in Georgia, and light brush under a loblolly pine stand in North Carolina. Samples were collected at distances from the fire site of 0.3 mile to 3.5 miles, except in Florida where the distance was 12 miles.

Certain properties of the size distributions of particles can be discovered by comparing the number distributions (fig. 11) with the mass distributions (fig. 12). Merging values from the two distributions, we found that the average diameter of particles in forest fire smoke is approximately 0.1 micron, and that this average is approximately the same for fires in all fuel types.

In general, only particles smaller than 10 microns can be expected to pose problems at distances greater than ½ to 1 mile from the source of production. Particles larger than 10 or 20 microns will usually be removed from the atmosphere by gravitational forces within this distance. There are, of course, exceptions caused by extreme

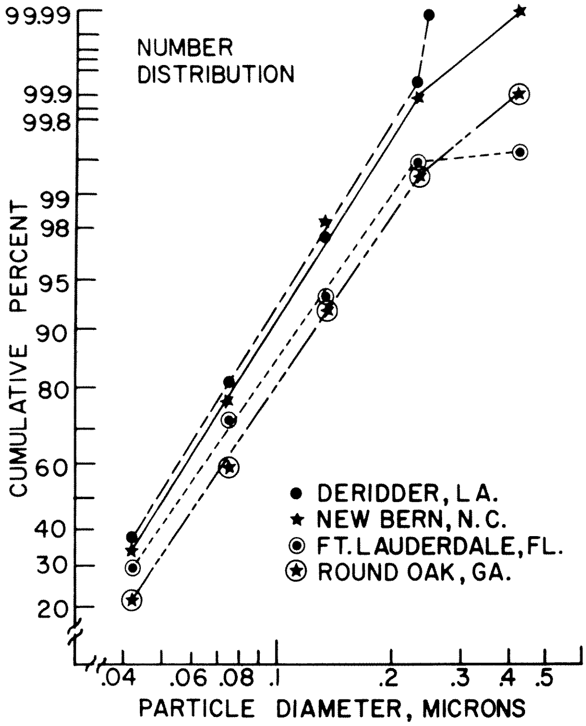


Figure 11. — Size distribution for particles smaller than about 0.5 micron. Distribution is based on numbers of particles.

windspeeds or by specialized particle growth conditions high in the atmosphere. Particles found by aircraft samplings of forest fire smoke plumes are rarely larger than 10 microns.

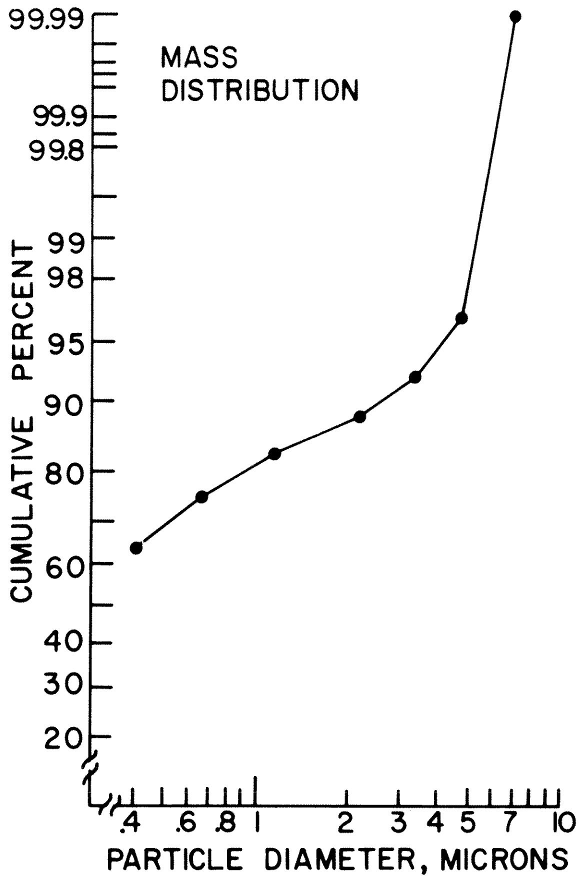


Figure 12. — Distribution of particles larger than 0.4 micron. Distribution is based on mass.

LITERATURE CITED

Ay, J. H., and M. Sichel

1976. Theoretical analysis of NO formation near the primary reaction zone in methane combustion. Combust. & Flame 25(1):1-15.

Balchum, Oscar J.

1973. Toxicological effects of ozone, oxidant, and hydrocarbons. Proc. Conf. Health Effects Air Pollut.:489-503. NAS-NRC, Washington, D.C.

Bartlett, Donald, Jr.

1973. Effects of carbon monoxide on human physiological processes. Proc. Conf. Health Effects Air Pollut.:103-126. NAS-NRC, Washington, D.C.

Brown, Arthur A., and Kenneth P. Davis

1973. Combustion of forest fuels, p. 155-182. *In* Forest fire: control and use. 2d ed. McGraw-Hill Book Co., Inc., New York.

Browne, F. L.

1963. Theories of the combustion of wood and its control. USDA For. Serv., For. Prod. Lab. Pap. 2136, 59 p. Madison, Wis.

Engel, Ronald E., H. Wilfried Goerke, Rauf Saygin, and others

1971. Air quality criteria for particulate matter. NATO, Comm. Challenges Modern Soc., N. 8, 257 p. Brussels, Belgium.

Evans, Leslie F., Nicholas K. King, David R. Packham, and others

1974. Ozone measurements in smoke from forest fires. Environ. Sci. & Tech. 8(1):75-76.

Foster, W. W.

1960. The size of wood smoke particles. Int. J. Air Pollut. 3:89-96.

Goss, J. R., and G. E. Miller, Jr.

1973. Study of abatement methods and meteorological conditions for optimum dispersion of particulates from field burning of rice straw. Spring open field burning trials. U.S. Dep. Commer., Natl. Tech. Inf. Serv. PB-235-796, 47 p. Springfield, Va.

Horvath, Steven M.

1973. Effects of carbon monoxide on human behavior. Proc. Conf. Health Effects Air Pollut.:127-144. NAS-NRC, Washington, D.C.

Hueter, F. Gordon, H. Wilfried Goerke, Necip A. Berksan, and others

1973. Air quality criteria for nitrogen oxides. NATO, Comm. Challenges Modern Soc., N. 15, 213 p. Brussels, Belgium.

Hueter, F. Gordon, H. Wilfried Goerke, Necip A. Berksan, and others

1974. Air quality criteria for photochemical oxidants and related hydrocarbons. NATO, Comm. Challenges Modern Soc., N. 29, 365 p. Brussels, Belgium.

Hueter, F. Gordon, H. Wilfried Goerke, Ayson Muezzinoglu, and others

1972. Air quality criteria for carbon monoxide. NATO, Comm. Challenges Modern Soc., N. 10, 264 p. Brussels, Belgium.

Jones, P. W.

1975. Final report on leaf burning emission program. Battelle Columbus Laboratories, Contract No. 63-02-1409, Task 28, Columbus, Ohio.

Kramer, Paul J., and Theodore T. Kozlowski

1960. Physiology of trees. McGraw-Hill Book Co., Inc., 642 p., New York.

MacArthur, D. A.

1966. Particle sizes in bush fire smoke. Aust. For.:274-278.

Murty Kanury, A.

1972. Ignition of cellulosic solids - a review. Fire Res. Abstr. & Rev. 14(1):24-52.

National Academy of Sciences

1972. Particulate polycyclic organic matter. Work performed pursuant to Contract No. CPA 70-42 with Environmental Protection Agency. 361 p., Washington, D.C.

National Academy of Sciences

1973. Sulfur oxides and particles. Proc. Conf. Health Effects Air Pollut. (Sess. 2):173-460. Washington, D.C.

National Academy of Sciences

1975. Air quality and stationary source emission control. Prepared for Committee on Public Works, U.S. Senate, 94th Congress, 1st Session. 909 p. Washington, D.C.

Sandberg, D. V., and R. E. Martin

1975. Particle sizes in slash fire smoke. USDA For. Serv. Res. Pap. PNW-199, 7 p. Pac. Northwest For. & Range Exp. Stn. Portland, Oreg.

Shy, Carl M.

1973. Human health consequences of nitrogen dioxide: a review. Proc. Conf. Health Effects Air Pollut.:363-405. NAS-NRC, Washington, D.C.

CHAPTER III

AIR QUALITY ADMINISTRATION

by

Andrew Searcy, Jr., Operations Research Analyst
Southern Forest Fire Laboratory
Southeastern Forest Experiment Station
USDA Forest Service
Macon, Georgia

This Chapter reviews the legislation and regulations passed to maintain air quality. It also introduces a voluntary decision procedure proposed for forestry smoke management.

THE FEDERAL CLEAN AIR ACTS

Interest in Federal clean air legislation began to accelerate in 1955 when Congress provided for investigations into the nature and extent of the Nation's air pollution problems. With the passage of the Clean Air Act of 1963 (PL 88-206), Congress encouraged the first air pollution abatement programs by providing Federal funds to assist in State and local control efforts and by establishing limited authority to abate interstate air pollution. Amendments to the 1963 Act in July 1967 increased the powers of the Secretary of the Department of Health, Education, and Welfare to implement air pollution abatement programs anywhere in the United States. The amendments included provisions to:

Request injunctions to abate emissions

Designate air quality control regions

Establish air quality standards for the above regions in the absence of effective State action

Enforce the above standards

Establish interstate air quality planning commissions; in lieu of action by the affected States (Stern 1971).

The Clean Air Act of 1970 greatly increased Federal powers and responsibilities. Section 101, paragraph (b) of the 1970 Clean Air Act lists as its purpose:

"To protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population" (U.S. Code: 42 U.S.C. S. 1857), while at the same time encouraging additional State and local regulations.

A REVIEW OF KEY SECTIONS OF THE 1970 CLEAN AIR ACT (PL 91-604) APPLICABLE TO FORESTRY PRESCRIBED BURNING

SECTION 108: AIR QUALITY CRITERIA AND CONTROL TECHNIQUES

The Environmental Protection Agency Administrator is directed to identify and publish a list of air pollutants. Included in this list is particulate matter.

SECTION 109: NATIONAL AMBIENT AIR QUALITY STANDARDS

The EPA Administrator is required to establish national primary and secondary ambient air quality standards for the pollutants identified in Section 108. The primary standard is set at a level necessary to protect the public health, while the secondary standard is set at a level to protect the public welfare from any known or anticipated adverse effects of a pollutant. Table 6 lists the levels of pollutants thus far identified by the standards as being adequate to protect the public health and welfare.

Table 6. — National primary and secondary ambient air quality standards 1/

Pollutant	Type of standard	Averaging time	Frequency parameter	Concentration	
				$\mu g/m^3$	Ppm
Carbon monoxide	Primary and secondary	1 hr	Annual maximum 2/	40,000	35.0
		8 hr	Annual maximum 2/	10,000	9.0
Hydrocarbons (nonmethane)	Primary and secondary	3 hr (6 to 9 a.m.)	Annual maximum 2/	3/ 160	3/ 0.24
Nitrogen dioxide	Primary and secondary	1 yr	Annual arithmetic mean	100	0.05
Photochemical oxidants	Primary and secondary	1 hr	Annual maximum 2/	160	0.08
Particulate matter	Primary	24 hr	Annual maximum 2/	260	—
		1 yr	Annual geometric mean	75	—
	Secondary	24 hr	Annual maximum 2/	150	—
		1 yr	Annual geometric mean	4/ 60	—
Sulfur dioxide	Primary	24 hr	Annual maximum 2/	365	0.14
		1 yr	Annual arithmetic mean	80	0.03
	Secondary	3 hr	Annual maximum 2/	1,300	0.05

1/ Adapted from Federal Register (1971).
2/ Not to be exceeded more than once per year.
3/ As a guide in devising implementation plans for achieving oxidant standards.
4/ As a guide to be used in assessing implementation plans for achieving the annual maximum 24-hour standard.

SECTION 110: IMPLEMENTATION PLANS

Each State must develop and submit for Federal approval a comprehensive plan identifying the strategy that the State intends to follow in order to attain and maintain the National Ambient Air Quality Standards. A State may revise its State Implementation Plan (SIP) at any time and, in turn, may be required to revise its plan by the Environmental Protection Agency (EPA) if it is found to be substantially inadequate.

SECTION 113: FEDERAL ENFORCEMENT

This Section also provides for Federal enforcement of an SIP where violations appear to be caused by a State's failure to enforce its own SIP. The EPA can initiate court actions against polluters violating an applicable provision of an SIP.

SECTION 114: INSPECTIONS, MONITORING, AND ENTRY

Onsite inspection of emission sources is authorized (U.S. Environmental Protection Agency 1970).

STATE AND LOCAL AIR QUALITY REGULATIONS 1/

Most States have granted variances from air pollution control rules to valid forestry burning practices. This could be done under the provisions of the Clean Air Act because these operations have not been identified as a *major* source of particulate matter.

1/ Portions of this Section were contributed by Joan B. Boilen, Attorney, Legal Support Branch, U. S. Environ. Prot. Agency, Reg. IV, Atlanta, Ga., 1975.

When emissions from major sources are reduced, lesser sources may be expected to receive more attention. Control of major sources alone may not be sufficient to achieve local ambient standards. Then, reduction of emissions from minor sources may be required. Some southern States are bringing prescription burning under control by requiring permits, and some have specified certain conditions limiting open burning. A few counties have curtailed all open burning.

The following are examples of some of the more stringent State regulations affecting forestry prescription burning in the South:

> In Arkansas, open burning is prohibited within specified distances of certain population centers except for fires used for purposes of forestry management, provided fires are set and burned when winds are blowing away from populated areas.
>
> In Florida, open burning is allowed between 9:00 a.m. and 1 hour before sunset with permission of the State Division of Forestry, or at other times when allowed by the Division and when dispersion of air pollutants is reasonably assured.
>
> In Georgia, counties with populations exceeding 65,000 allow open burning only if adequate disposal facilities are not reasonably available. In all counties, no smoke of a shade darker than a No. 2 on a Ringelmann chart (a means by which opacity of smoke plumes is judged by visual observation) is permitted—except for a reasonable period to get the fire started.
>
> In South Carolina, open burning specifically for forestry management is excepted from a general ban when practices acceptable to the State Board of Health and Environmental Control are followed, and when no undersirable levels of pollutants are or will be created.
>
> In Tennessee, forestry prescription burning exceptions include provisions that no public nuisance is created, and that no land, air, or water traffic hazard is created. Distances from certain specified land-use areas (e.g., 1/2 mile from a secondary highway) are also imposed as restrictions on burning.

The importance of having an up-to-date knowledge of traditional State and local air quality regulatory requirements is evident from these examples. In addition, the forestry smoke manager needs firsthand knowledge of specific concerns in each Air Quality Control Region (AQCR) and in any Air Quality Maintenance Area (AQMA) where he works.

AIR QUALITY CONTROL REGIONS AND MAINTENANCE AREAS [2/]

The primary air quality administrative area is the Air Quality Control Region (AQCR). These areas were designated on the basis of geographical and meteorological considerations, as well as political boundaries. For this reason, they may transcend State or county borders.

Initially, in 1971 these AQCR's were classified Priority I, II, or III based upon existing air quality to assist States in planning. In each AQCR the sources of air pollution were identified and control measures adopted that, after analysis, were felt to be sufficient to provide for attainment of the National Ambient Standards upon implementation.

In 1973, a court decision required EPA to disapprove all State Implementation Plans (SIP's) for not providing for maintenance of the ambient standards beyond the attainment date of mid-1975. The court held that SIP's had addressed the growth of pollution sources and their related air emissions only until the time when standards would be attained, and not beyond. Further, the court made clear the Clean Air Act required the development of a plan that included provisions for continuing attainment and maintenance of the ambient standards well beyond the attainment date. In response to the court's decision, EPA developed procedures for each State to use in assessing the maintenance issue. Each State was asked to review the air quality within its jurisdiction and identify those areas (usually counties) that, due to anticipated growth, had the potential to violate the ambient standards during the forthcoming 10-year period. These areas were identified as Air Quality Maintenance Areas (AQMA's).

In most cases, the area designated as an AQMA is only a portion of an AQCR. Usually the AQMA is urban as well as the surrounding area expected to be affected by the same growth potential. Designation of the AQMA's was completed in September 1975. Much emphasis has been placed on these AQMA's by each State in their reviews of growth and its impact on air pollution. The States are assessing strategies that, upon application, will provide continuous maintenance of the ambient standards.

2/ Portions of this Section were contributed by William M. Burch, Chief, Air Strategy Dev. Sect., Air Programs Branch, Air and Hazardous Mater. Div., U.S. Environ. Prot. Agency, Reg. IV, Atlanta, Ga., 1975.

PREVENTION OF SIGNIFICANT DETERIORATION

Additional court decisions involving interpretation of the Clean Air Act resulted in the development of the EPA program to prevent significant deterioration (PSD) of air quality. The Administrator put this program into effect on December 5, 1974 (Federal Register 1974).

These PSD regulations combined the concept of area classification with new source review procedures and the application of best available control technology. The preconstruction review of all new and modified sources now including 19 major categories (but not forestry burning) is designed to prevent their violating allowable increments of deterioration and to assure the employment of best available control technology (Federal Register 1975). States are being encouraged to accept a delegation of authority to implement this review process fully.

While the regulations are directed to specifically named stationary sources, their importance to other sources lies in area classification by classes.

The regulations stated that, effective January 6, 1975, all areas are designated Class II and restrict deterioration to that associated with normal, well-controlled growth. With the 1974 air quality regulations as a baseline, States may decide if areas should remain Class II or should be either Class I that restricts deterioration to a minimum, or Class III that levies no additional restrictions beyond State plan requirements and considers any deterioration as insignificant as long as no national standards are violated. These class designations differ from the priority classification discussed earlier in that they indicate levels of air quality to be maintained, whereas the priority classifications indicate the urgency to apply pollution abatement measures to the areas so designated.

A VOLUNTARY DECISION PROCEDURE PROPOSED FOR FORESTRY SMOKE MANAGEMENT [3/]

Even though the main focus of air quality regulations has been on stationary and automotive sources of emissions, southern forest managers have sought a method by which they may voluntarily help to avoid unwanted environmental consequences from prescription burning. In the preceding sections of this Chapter, we have reviewed an evolving framework of air quality administration. In Chapter I we discussed alternatives to burning, and in Chapter II we examined the characteristics of forestry smoke likely to bear on future increased regulatory interest, locale by locale.

A single forestry burn will seldom be an important emitter more than a few hours on 1 day every 3 or 4 years. It may, however, contribute emissions of consequence to a given atmosphere when the pollution load is already high, or when concentrations temporarily exceed locally acceptable levels. Because they are based on long-term health studies, regulations and standards established for stationary and mobile sources of emissions do not lend themselves well to decision procedures for these transitory forestry sources. For example, standards are usually expressed as concentrations averaged over times longer than a forestry burn would last. Because of this, a time/concentration adjustment could be made which would still be within established standards; the adjusted concentration could, however, be intolerable when judged by other criteria such as highway safety or personal respiratory difficulties.

In some areas of the United States, carrying capacity of the atmosphere is estimated within certain boundaries. This approach is called the "Tank Concept" in that this supposed finite atmosphere is regarded as having limiting "walls" and a "lid." We have rejected this concept because it does not adequately represent actual dispersion, particularly in the initial stages.

Our proposal will be fully presented in Chapter VI, after discussions in Chapters IV and V on the important variables affecting the procedure. We believe the proposal will lend itself well to self-regulation or to agency administration. It emphasizes decisions for the single forestry burn, but also recognizes multiple contributions from other forestry burning or fixed sources. A major gain in air quality will be achieved in some locales if the procedures for multiple-source forestry burns are applied by mutual agreement between burners.

Currently the best available control technology (also used in many similar instances) is to limit the escape of particulate matter into the atmosphere, regardless of the size or chemical composition of the particulate matter. We have

3/ Contributed by Southern Forest Fire Laboratory personnel who developed the Decision-Logic presented in Chapter VI.

adapted this control technology to short-term or instantaneous concentrations.

Very small chemically reactive particles have a greater potential to impair health than large chemically inert particles. Regulatory agencies are placing increased emphasis on controlling more harmful components. Limiting strategies under development will thus likely be more specific.

While many tedious operations are needed for decisions in complex situations, the basic procedure involves just five main steps:

1. Predicting a smoke plume trajectory

2. Identifying key targets along this trajectory (in this text, targets denote locations where smoke concentrations are more likely to have unwanted effects; e.g.: an AQMA, a "sensitive" community, an airport, a road, a highway, a townsite, etc.)

3. Selecting a maximum acceptable particulate matter concentration for each key target identified

4. Determining the "background" pollutant level within the target area, then adding this to the prescribed fire concentration predicted to reach the zone where the target is identified

5. Comparing the maximum acceptable concentration in No. 3 with the total concentration in No. 4.

Selection of a maximum acceptable concentration in No. 3 above can be either as determined by a special ambient air quality requirement in effect or desired, or as dictated by a need to maintain a certain level of visibility. In the procedure described in Chapter VI, either type of value can be selected by the decisionmaker. There is an implication in the literature that public complaints are more closely associated with visibility reductions and with effects of visibility impairment on highway and air traffic safety. Decisionmakers arriving at acceptable concentrations may also be influenced by the current indication that visibility-determined concentrations for total suspended particulate matter are more stringent than those suggested by published human health effects (U.S. Department of Health, Education, and Welfare 1969).

Figure 13. — A first step in smoke management is to identify potential targets — areas that might be adversely affected by the smoke from a prescribed burn.

LITERATURE CITED

Federal Register

1971. National primary and secondary ambient air quality standards. Fed. Regist. 36(84): 8186-8201.

Federal Register

1974. Approval and promulgation of implementation plans. Fed. Regist. 39(235):42510-42517.

Federal Register

1975. Approval and promulgation of implementation plans. Fed. Regist. 40(176):42011-42012.

Stern, Arthur C.

1971. Air and water pollution quality standards. Part 1: Air pollution standards, p. 4-1 through 4-22. *In* Herbert F. Lund (ed.), Industrial pollution control handbook. McGraw-Hill Book Co., Inc., New York.

U.S. Department of Health, Education, and Welfare

1969. Air quality criteria for particulate matter. Natl. Air Pollut. Control Adm. Publ. No. AP-49, 211 p. Natl. Air Pollut. Control Adm., U.S. Dep. Health, Educ., and Welfare, Washington, D.C.

CHAPTER IV
FUELS, FIRE BEHAVIOR, AND EMISSIONS

by
Ragnar W. Johansen, Research Forester
W. Henry McNab, Research Forester
Walter A. Hough, Research Forester
M. Boyd Edwards, Jr., Research Botanist
Southern Forest Fire Laboratory
Southeastern Forest Experiment Station
USDA Forest Service
Macon, Georgia

This Chapter prepares you to predict the amount of particulate matter emitted and the rate of heat release from deliberate burning of forest fuel. Making these predictions requires estimates of the amount of fuel that will burn, the rate at which fire will spread, the amount of particulate matter that evolves per ton of fuel burned (called emission factor), and the heat yield of the fuel.

The material presented is organized as follows: variables affecting emissions and fire phases, heat release rate, emission rate, specific information by fuel types, and a conclusion. Although many fuel complexes are present in the Southeast, only the major types in which most of the prescription burning is done will be discussed. The identification of each fuel type is generally based on its vegetative cover and, to some extent, on the ecological province it occupies. The major fuel types discussed in separate sections are: grasses, pine needle litter, palmetto-gallberry, light brush, and pine logging debris.

VARIABLES AFFECTING EMISSIONS AND FIRE PHASES

Emissions of particulate matter are influenced by many variables as are fire phases. These are reflected in fuel loading, rate of spread, burning method, and combustion stage.

FUEL LOADING

It is important to understand the difference between *total* fuel and *available* fuel. *Total* fuel is the entire accumulation of vegetative matter, living or dead, that could possibly burn if properly conditioned. *Available* fuel is that portion of the total fuel that will be consumed by a fire during the burning period following ignition. While available fuel is needed in the emission rate and heat release rate equations, total fuel must be estimated before the available value can be calculated.

Three layers of litter will eventually develop on an undisturbed forest floor: a top litter layer (L), a fermentation layer (F), and a humus layer (H). When sampling, the two upper litter layers (L + F) can be grouped. These L + F layers account for most of the fuel consumed during prescription burns (Hough 1968). During droughts, considerable humus can also burn. Live vegetation in the understory must also be accounted for since it will be consumed in varying degrees, depending on the burning conditions.

RATE OF SPREAD

Rate of fire spread must be known to compute *particulate matter emission rate* and *heat release rate to the atmosphere* from prescribed fire.

The rate at which fire advances through a forest fuel usually depends on windspeed and on size, arrangement, and moisture content of the surface litter and understory fuel. An exception is when the fire is backing against the wind. In that case differences in windspeed have a negligible effect on spread rate, and a windspeed of zero should be used when entering the rate of spread tables.

Fire spread rates vary by fuel type because of differences in fuel type and arrangement. They are, therefore, discussed individually in the Guidebook.

BURNING METHOD

The burning method employed will depend upon the kind of area to be burned and the burning conditions. There are four main categories of burning method:

Backing fires are those that are ignited on the downwind side of an area and permitted to spread (or "back") against the wind.

Heading fires are ignited on the upwind side of an area and permitted to spread (or "head") with the wind.

Sometimes, *backing* or *heading fires* are ignited in strips and allowed to burn together.

Ring fires are ignited on all sides of an area to be burned.

Area-ignited fires or *simultaneous-ignition fires* are those that are ignited in many places at about the same time to result in many small fires burning together.

Often, combinations of these categories are used.

Burning is generally done in two kinds of areas. In the first, a tree overstory exists and considerable understory and/or litter are to be removed. The fuel is generally natural plant accumulations that increase with time, although logging residue from thinnings may also be present. In the second kind of area a tree overstory no longer exists, but there is fuel on the ground. This fuel results from clearcut logging or brush clearing.

When burning under a tree overstory, timber managers must be sure their fires do not seriously damage or destroy crop trees. A manager usually waits for those days when winds are likely to remain steady for the burning period. He can then ignite the downwind side of his area and allow the fire to back slowly against the wind. If fuel loading is not excessive, intensity of a heading fire may be acceptably low.

When burning areas free of an overstory, there is obviously no need for concern about damage to an overstory. The main purpose of such burns is to consume as much fuel as possible on the area. Only precautions to prevent fire escape, to minimize air pollution downwind, to avoid soil damage and unwanted runoff of ash, etc., need be considered. High-intensity heading fires are generally used when the fuel is dispersed over the area. Such fires will usually jump gaps in fuel continuity.

There are times, especially in land-clearing operations, when much of the fuel exceeds 2 inches in diameter. If disposal of the large material by burning is desired, some form of piling is necessary. Concentrating the fine fuel with the large, allowing the entire mass to dry, and igniting the pile perimeters quickly to get rapid heat buildup will permit the large fuel elements to be ignited and eventually consumed.

Burning method affects rate of fire spread, rate of particulate matter emission, and amount of fuel consumed. In heading fires, a relatively large amount of fuel is consumed during the residual combustion stage, and more particulate matter is produced per unit of fuel burned.

COMBUSTION STAGES

We will discuss combustion in two main stages: *advancing-front stage* and *residual stage.* These stages may be broken down into substages to further characterize the fire behavior. For example, the *advancing-front stage* is usually a *flaming front,* but can also be a *smoldering front.* For the burning situations covered in this Guidebook, only the two main stages are important to determining separate emission factors (EF) and emission rates (ER) due to marked differences in quantities of particulate matter emitted in these stages.

FIRE PHASES

For convenience, we have separated fires into two phases: *convective-lift phase* and *no-convective-lift phase.* The *convective-lift phase* is when most emissions are entrained into a definite convection column because of heat being released from the fire. The *no-convective-lift phase* is when most emissions are not entrained into a definite convection column. Heat release rate will be of consequence to the plume rise of the *convective-lift phase,* but of no consequence to the *no-convective-lift phase.*

MINIMIZING DURATION OF THE NO-CONVECTIVE-LIFT FIRE PHASE

Long-duration residual combustion involves humus, organic soil, and large fuel elements such as stumps, snags, and logs. Decaying stumps and snags exceeding 10 inches in diameter contribute most to long-duration residual combustion. Large pieces of sound wood are not easily ignited during the relatively brief exposure to the flaming front of a prescribed fire. When ignition does occur, the rapid departure of reinforcing heat from surrounding sources causes quick flameout, and smoldering in sound wood is short lived. This Guidebook does not address the problem of long-duration residual combustion in detail because the great variability does not now permit a standard handling procedure. There are, however, some safeguards that can be observed to minimize troublesome emissions during the associated no-convective-lift phase of fires.

Rate of stump deterioration following timber cutting was observed in the Coastal Plains of Georgia (unpublished data, Southeastern Forest Experiment Station). Data from this study permit estimation of the extent of rot in stumps if the time of cutting is known:

Year after cutting	Depth of decay (Inches)
1	0.5
2	1.5 – 2.5
3	4.0 – 5.0
4	6.0

To minimize the amount and duration of residual combustion, take these actions:

Fell dead snags.

In cutting operations, keep stump height as low as possible to maximize moisture content of decaying stumpwood and speed decay.

Burn only when stump moisture content is high, as soon after a heavy rainfall as possible.

Scatter large, sound wood material.

As necessary, provide for mopup.

TOTAL LITTER LAYER MOISTURE CONTENT

Fuel moisture is constantly changing, and the changes must be monitored. Both wetting and drying moisture curves for 10-hour timelag fuels are contained in the National Fire-Danger Rating System (NFDRS) (Deeming and others 1972), but they do not apply to pine needle litter. The *wetting curves* are based on moisture absorbed by wood dowels that respond much slower than does pine needle litter. The *drying curves* approach 10 to 15 percent moisture content in about 7 days—lower than measured moisture contents in heavy slash pine litter layers 7 days after a rain. Palmetto-gallberry, grass, and pine needle litter types all need more accurate litter moisture estimates. More appropriate curves were, therefore, developed using data from experimentally burned plots in the South.

Multiple-regression analysis showed that total litter layer moisture content could be predicted with acceptable accuracy from days since rain and total litter layer dry weight (Hough 1976). In the presence of these variables, relative humidity did not improve predictions. Using Hough's (1976) equations, table 7 was developed to show rates of drying for litter. To enter the table, one must know the age of rough and yesterday's total litter layer moisture content. The value shown in the table is subtracted from yesterday's value to estimate today's total litter layer moisture content.

During wet, rainy periods forest litter moisture content increases. Moisture retention capacity of total forest litter layers has been found to be up to 300 percent of dry weight (Swank and others 1972, Metz 1958, Helvey 1964, Van Wagner 1970). Metz found this maximum moisture content only after prolonged rainfall, indicating the importance of rainfall duration. This need was also shown by Paul,[4/] who found that maximum water uptake for pine litter occurs in 10 to 12 hours. A single curve of total litter layer moisture content versus duration of precipitation was used to construct a table that gives a reasonable estimate of moisture content *increases* in the litter fuel bed (table 8).

4/ Paul, James T. 1967. Influence of rate of rainfall on pine litter moisture content. Unpublished report. Southeast. For. Exp. Stn., Macon, Ga.

Table 7. — Daily correction to the total litter layer moisture content for drying

Age of rough (years)	Yesterday's total litter layer moisture content (percent)																
	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-55	56-65	66-89	90-109	110-129	130-164	165-199	200-200+
	Percent																
1 to 2	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-13	-18	-25	-40	-60	-75	-80
3 to 10			0	-1	-2	-3	-4	-5	-6	-7	-9	-12	-16	-25	-50	-70	-75
11 to 25					0	-1	-2	-3	-4	-5	-6	-9	-12	-17	-40	-65	-70

Table 8. — Correction to total litter layer moisture content for wetting due to precipitation

Precipitation duration (hours)	Yesterday's total litter layer moisture content (percent) 1/				
	10-30	31-50	51-70	71-90	91+
	Percent				
1	+ 75	+ 55	+ 35	+ 15	0
2	+100	+ 80	+ 60	+ 40	+ 25
3	+120	+100	+ 80	+ 60	+ 45
4-5	+135	+115	+ 95	+ 75	+ 60
6-8	+150	+130	+110	+ 90	+ 75
9-12	+165	+145	+125	+105	+ 90
12-24	+220	+200	+180	+160	+145

1/ A value of 250 percent is the practical maximum that should be used. If yesterday's total litter moisture content, plus the correction for precipitation exceeds 250, enter 250 on records.

To use table 8, all that is needed is duration of rainfall and a value for yesterday's total litter layer moisture content. The value taken from the table is added to yesterday's total litter layer moisture content to give the moisture content of the layer today. Rainfall duration should be obtained from nearby weather stations, or from fire-danger rating stations that maintain rainfall duration records. A form (table 9) was designed to keep track of daily changes in total litter layer moisture content. This record should be started when there has been abundant rainfall for 8 or more hours so that an initial value of 250 percent for today's litter moisture can be assigned opposite the appropriate date and fuel loading class. Should a time of year be selected for beginning to track the total litter layer moisture when the chance for having 8 hours of continuous rain is remote, pick a day when at least 0.25 inch of rainfall occurs and assign a litter moisture value of 100 for that day.

If a number of stands have different ages of rough and are being considered for prescription

Table 9. — Daily record of total litter layer moisture content

Day of month	Age of needle rough	Correction for daily drying	Precipitation			Correction due to rain duration	Yesterday's litter moisture content	Today's total litter moisture content
			Begin	End	Duration			
	Years	Percent	Time	Time	Hours	Percent	Percent	Percent
1	1- 2	—				+		
	3-10	—				+		
	11-25	—				+		
2	1- 2	—				+		
	3-10	—				+		
	11-25	—				+		
3	1- 2	—				+		
	3-10	—				+		
	11-25	—				+		
4	1- 2	—				+		
	3-10	—				+		
	11-25	—				+		
Daily record continues to end of month								

burning, the daily drying rates will have to be maintained for each age class.

Steps and tables needed to determine total litter layer moisture content are:

1. Obtain records of daily rainfall duration from the nearest weather station or fire-danger rating station.

2. Beginning with the day of interest (today), search the records backward until a day is found on which rainfall duration exceeded 8 hours or at least ¼ inch of rain fell.

3. Locate that date on table 9 and enter 250 or 100 in the "Today's" column for that day's litter moisture.

4. Compute daily change in fuel moisture using instructions found on that form until today's date is reached. After these initial calculations are completed, it is suggested that daily calculations of total fuel moisture be made to maintain a current record.

5. When rain has fallen in the past 24 hours, go directly to Step 7. When it has not, go to Step 6.

6a. Record age of rough: ________ years.

b. Obtain yesterday's total litter layer moisture content from table 9.

c. Read correction factor due to drying from table 7.

d. Record factor in correction for daily drying column opposite today's date on table 9.

e. Subtract drying correction from yesterday's litter moisture.

f. Record answer in today's total litter moisture content column on table 9.

7. To increase yesterday's total litter moisture content by a correction factor for rain:

a. Record rain duration for past 24 hours: ________ hours.

b. Obtain yesterday's litter layer moisture content from table 9: ________ percent.

c. Read correction for rain in table 8.

d. Record correction due to rain duration opposite today's date and proper age of rough on table 9.

e. Add rain correction to yesterday's litter moisture.

f. Record answer in today's total litter moisture content column on table 9.

HEAT RELEASE RATE TO THE ATMOSPHERE

The rate of heat released to the atmosphere (HRR) by flames in an advancing-front combustion stage is needed to determine how high a smoke plume will rise during the convective-lift phase of the fire. Heat released from the residual stage of combustion is expected to be of importance in some situations, but is only negligible for those situations covered in this Guidebook.

The total heat of combustion of ovendry forest fuel burned in a bomb calorimeter averages 8,600 British thermal units (Btu) per pound and is a maximum value. Considerable heat is lost when these fuels are burned in the forest in their natural state. There, heat yield varies from 5,000 to 7,000 Btu. Losses are due to such phenomena as incomplete combustion, radiation, and the presence of moisture in the fuel. Brown and Davis (1973) report that 6,300 Btu is a good average for fuel conditions and types of fire encountered when prescription burning southern fuels. Further details will be covered in the *Forestry Smoke Management Sourcebook.*

The calculations for heat release rate (HRR) are:

1. To simplify the heat release rate equation and provide the dimensional units used in Chapters V and VI, we have determined a factor that includes the heat yield constant and converts from English to metric units—0.0012.

2. The heat release rate equation with this conversion factor is:

$$HRR = 0.0012\, y_A\, wrL \qquad (1)$$

where HRR = heat release rate to the atmosphere in megacalories per second

y_A = fractional part of available fuel involved in the advancing-front combustion stage (range 0.01 to 1.00)

w = weight of available fuel in tons per acre

r = rate of spread in feet per minute

L = length of fire front in feet.

PARTICULATE MATTER EMISSION RATE

The particulate matter emission rate (ER) is the weight of suspended particulate matter produced per unit length of line per unit of time. This rate is needed to determine how much will be transported and dispersed to targets downwind from a burn. An emission factor (EF) will be used in this calculation. Each fuel type has been assigned a constant emission factor that reflects its unique characteristics. Within fuel types, fuel arrangement and moisture patterns are known to influence the EF. We do not have sufficient data to calculate such variations precisely, and the calculations would be cumbersome.

The manner in which particulate matter evolves from a prescription burn can differ measurably, depending upon available fuel and the manner of burning. All backing fires, and those heading fires burning on areas having low fuel loadings (1- to 2-year-old roughs), consume most of the fuel in the advancing-front combustion stage. However, heading fires in older roughs or in broadcast logging debris consume only 50 to 80 percent of the fuel during the advancing-front combustion stage. The available fuel remaining in heading fires is consumed in the residual combustion stage. In the case of heading fires in older roughs and logging debris, there is enough heat in the advancing-front combustion stage to entrain part of the residual stage emissions into a convection column; after the heat diminishes, emissions from the residual combustion stage become associated only with the no-convective-lift fire phase.

Contributions of emissions from the two combustion stages to the convective-lift fire phase and to the no-convective-lift fire phase are summarized by fuel type and burning method (table 10). More detailed information on emission factors (EF) is in separate sections to follow for each fuel type.

Table 10. — Contribution of emissions from combustion stages to fire phases

Fuel type and burning method	Fire phases	
	Convective-lift (CL) phase	No-convective-lift (NCL) phase
Grass with pine overstory:		
all burning methods	Advancing-front stage EF = 15 lb/ton	None
Pine needle litter and/or light brush with age of rough 2 years and less:		
all burning methods	Advancing-front stage EF = 50 lb/ton	None
Pine needle litter and/or light brush with age of rough more than 2 years:		
backing fires	Advancing-front stage EF = 50 lb/ton	None
heading fires	Advancing-front stage EF = 50 lb/ton and Residual stage EF = 180 lb/ton	Residual stage EF = 180 lb/ton
Palmetto-gallberry with age of rough 2 years and less:		
all burning methods	Advancing-front stage EF = 25 lb/ton	None
Palmetto-gallberry with age of rough more than 2 years:		
backing fires	Advancing-front stage EF = 25 lb/ton	None
heading fires	Advancing-front stage EF = 25 lb/ton and Residual stage EF = 125 lb/ton	Residual stage EF = 125 lb/ton
Unpiled logging debris:		
all burning methods	Advancing-front stage EF = 35 lb/ton and Residual stage EF = 180 lb/ton	Residual stage EF = 180 lb/ton

A factor of 570 is needed to convert from the familiar English units (pounds, acres, feet) used to describe our fuel, fire movement, and emission factor (EF) to the metric units needed in the emission rate (ER) dispersion equation in Chapters V and VI.

The equation for the advancing-front combustion stage particulate matter emission rate (ER_A) is:

$$ER_A = 570\, y_A wrEF_A \qquad (2)$$

where ER_A = particulate matter emission rate in micrograms per meter-second

y_A = fractional part of available fuel involved in the advancing-front combustion stage (range 0.01 to 1.00)

w = weight of available fuel in tons per acre

r = rate of fire spread in feet per minute

EF_A = emission factor in pounds per ton for the advancing-front combustion stage.

The particulate matter emission rate (ER_R) for the residual combustion stage can be calculated in the same manner as for the advancing-front stage of combustion:

$$ER_R = 570\, y_R wrEF_R \qquad (3)$$

where ER_R = particulate matter emission rate in micrograms per meter-second

y_R = fractional part of available fuel remaining to be involved in the residual combustion stage (or $1 - y_A$)

w = weight of available fuel in tons per acre

r = rate of fire spread in feet per minute

EF_R = emission factor in pounds per ton for the residual combustion stage.

For the convective-lift phase of heading fires where the total emissions must include those from both the advancing-front stage and the residual stage of combustion, a total emission rate is calculated as follows:

$$ER_{A+R} = ER_A + ER_R \qquad (4)$$

Fuel types are discussed individually in the following sections. Since all of the referenced tables must be used in Chapter VI, they are presented therein for convenience of users, and will only be cited here to avoid repetition and save space.

GRASS WITH PINE OVERSTORY FUEL TYPE

DESCRIPTION

Loblolly, slash, and longleaf pines in the South are normally associated with various grasses, most of which form bunches rather than turf.

Figure 14. — Grass with pine overstory fuel type.

Grasses of the genus *Andropogon*—including broomsedge (A. *virginicus* L.), little bluestem (A. *scoparius* Michx.), and slender bluestem (A. *tener* Muhl.)—are dominant on all of the moist sites where longleaf has been succeeded by slash and loblolly pines, or where sites have been extensively disturbed by cultivation or site preparation such as disking, chopping, and bedding (Grelen 1962). On drier, sandy sites where longleaf pines predominate, wiregrass (*Aristida* spp.) dominates the site.

Where grass makes up a significant portion of the total fuel loading (estimated to exceed 50 percent by weight), and the presence of shrubs is insignificant, the fuel type will be designated "grass." Where a dense pine overstory exists, the fuel type is considered the same as a "pine needle litter type" after age of rough is more than 1 year.

FUEL LOADING

Grass fuels in forested stands are unique. The greatest accumulation occurs after the first growing season following a fire and continues to decrease thereafter. The decrease is due to the smothering effect of accumulating needles shed from a pine overstory and the shading effect of a developing brush understory. Total grass accumulation in tons per acre is presented in table VI-F-1, page 105, for easy use. For grass, available fuel will be considered equal to total fuel. The available fuel in any pine needle accumulation must also be estimated (table VI-F-5, page 109; or table VI-F-6, page 110; and table VI-F-7, page 111).

EMISSION FACTOR

Evidence available from the experimental burning of many grass species suggests an emission factor of 15 (pounds of particulate matter per ton of fuel) for prescribed burning with heading or backing fires. We are assuming that most of this burning will take place when fuel moisture is between 4 and 15 percent (dry basis), and that all fuel is consumed during the advancing-front combustion stage.

RATE OF SPREAD

The estimating system that best represents measured rate-of-spread values in grass fuel was calculated from the Rothermel rate-of-spread equation using typical grass fuel characteristics (Rothermel 1972). Calculated values have been converted to tabular form so that the only variables needed to determine the rate of spread are fine fuel moisture and windspeed (table VI-F-4, page 108). Actual fuel moisture can be derived from table VI-F-2 (page 106) where the fuel moisture is shown to be a function of ambient temperature, relative humidity, and cloud cover. The windspeed used should be that at midflame height. This value can be approximated by obtaining the value reported from a 20-foot tower at the nearest fire-danger rating station and dividing that value by 4.

Data from table VI-F-4 (page 108) should be used only for sites with slopes of 20 percent or less. The table is suitable for the Coastal Plains of the South where most prescription burning is done.

Fire travel in feet per minute from the table can be converted to miles per hour as follows:

$$\text{mph} = \frac{\text{feet per minute}}{88}$$

PINE NEEDLE LITTER AND LIGHT BRUSH FUEL TYPES

The forest floor of pine stands having light brush understories may appear quite different from that of a pine stand without an understory, but knowledge gained from studying fuel buildup and fire behavior in these stands shows them to be very similar. They will, therefore, be treated as a single fuel complex.

DESCRIPTION

Pine Needle Litter

In well-stocked pine stands, understory grasses and shrubs are drastically reduced after crowns close due to overhead shading from the pine canopy, competition from pine roots, and the blanketing effect of the shedding pine needles. The areas are generally parklike with a blanket of pine needles covering the soil surface. Understory shrubs that are present are sparsely scattered, and grass is found mainly in stand openings.

This type usually develops where previously cultivated land has reverted to pine forest, and where sites have been carefully prepared by plowing, disking, or bedding prior to pine regeneration.

Light Brush

This type is found throughout the Piedmont and Upper Coastal Plain regions of the Southern States. The fuel mixture consists of grasses, forbs, pine needle litter (usually loblolly pine), deciduous shrubs, and small deciduous trees such as blackgum (*Nyssa sylvatica* Marsh.), sweetgum (*Liquidambar styraciflua* L.), red maple (*Acer rubrum* L.), oaks (*Quercus* spp.), etc. There may also be some scattered nondeciduous shrubs, such as wax myrtle (*Myrica cerifera* L.) or holly (*Ilex opaca* Ait.).

Figure 15. — Backing fire in pine needle litter fuel type.

During the winter and early spring when prescription burning is usually done, only the naked stems of the shrubs are standing. All the leaves have fallen and become part of the litter layer—together with the grass, forbs, and pine needles. Most of the available fuel is in this layer.

FUEL LOADING

Because rate of pine needle accumulation under slash pine stands differs considerably from accumulations under loblolly or loblolly-longleaf stands, separate tables for predicting fuel loading will be presented for each.

Litter accumulation is the same whether an understory does or does not exist. In stands where no understory exists, only the litter fuel need be considered as total fuel for the area. Where understory fuels will be consumed by a prescribed burn, the two fuel fractions must be summed to estimate total fuel.

Slash Pine Litter Total Fuel Estimate

Equations describing the relationships between litter accumulation on the forest floor, basal area, and age of rough have been reported by McNab and Edwards (1976). For field use, the ovendry values are presented in table VI-F-5 (page 109). This table shows, for example, that in a 5-year-old rough where the stand basal area is 70 square feet, there would be a *total* litter accumulation of 6.1 tons.

Slash Pine Litter Available Fuel Estimate

The portion of total fuel that is *available* for consumption by a prescribed fire is directly correlated with the moisture content of the fuel. By estimating *total* loading from table VI-F-5 (page 109) and deriving the total litter layer moisture content (percent), the amount of fuel *available* for burning can be read from the center of table VI-F-7 (page 111). To use the table you must know the total litter layer moisture content, discussed under VARIABLES AFFECTING EMISSIONS AND FIRE PHASES.

Loblolly Pine Litter And Light Brush Total Fuel Estimate

The primary fuel consumed during a prescribed burn in this fuel type is loblolly pine needles, or a mixture of loblolly and longleaf or loblolly and shortleaf needles—possibly with some hardwood brush leaves.

High densities of young hardwood and brush stems are present in this type. During the growing season, the brush is very evident due to the presence of their green leaves; but during dormancy, when all the leaves have been shed, only naked stems are evident. Although they are usually killed by the heat, the stems are not generally consumed in prescribed burns.

An insufficient number of loblolly pine plots were sampled to develop a *total* litter prediction equation as was done with slash pine litter. The slash pine litter model was tried for estimating loblolly litter accumulations using the loblolly stand parameters of basal area and age of rough. In every case, the slash pine model overestimated the actual loblolly weights. We decided to use the model and calculate an error factor by regression:

$$\text{Error factor} = 1 + \left[\frac{3.74 + 4.49\ (\text{age of rough})}{100}\right]$$

Then,

$$\text{Loblolly litter weight} = \frac{\text{Slash pine litter weight}}{\text{Error factor}}$$

Using values from slash pine litter data and the error factor equation, loblolly pine litter accumulations were computed and listed in table VI-F-6 (page 110). Considerable estimation error may occur when using values in excess of 5 tons per acre because those values are extrapolated well beyond the weights actually measured on our limited sample plots.

Loblolly Pine Litter and Light Brush Available Fuel Estimates

Loblolly litter can now be determined from table VI-F-7 (page 111) using the total weight values derived from table VI-F-6 (page 110) and total litter layer moisture content as earlier discussed under VARIABLES AFFECTING EMISSIONS AND FIRE PHASES.

EMISSION FACTOR FOR SLASH AND LOBLOLLY PINE LITTER AND LIGHT BRUSH FUEL TYPES

Particulate matter emissions from burning pine needle litter were derived from laboratory and field experiments by Southern Forest Fire Laboratory personnel.

Backing Fires

As fuel moisture increases, so does emission of particulate matter. Backing fires in laboratory-burned loblolly needle beds at a moisture content of 6 to 10 percent had an emission factor of 17 pounds per ton of fuel consumed; but at a 19 percent moisture content, the value was 28 pounds.

Particulate matter emissions measured on several backing fires in slash pine plantations averaged approximately 50 pounds per ton of consumed fuel. This higher emission factor is thought to be due to differences in moisture content of different litter layers.

Until further knowledge is gained to reconcile the differences in particulate matter emissions between laboratory and field burns, and to account for the effect of fuel moisture, an emission factor of 50 pounds of particulate matter per ton of needles consumed should be used. Most emissions are from the slow-moving flaming portion of the fire.

Heading Fires

Emissions from heading fires moving through pine needle fuel (ER_{A+R}) usually come from both the advancing-front combustion stage and the residual combustion stage that take place immediately after passage of the advancing front. Thus, $ER_{A+R} = ER_A + ER_R$.

In the advancing-front stage the emission factor would be identical to that of backing fires, 50 pounds per ton of fuel consumed; but the emission factor in the residual combustion stage could be up to 180 pounds. These data are based on the burning of small fuel beds in a laboratory, but are the best available.

Where litter buildup is low, as in a 1- to 2-year-old rough, emissions from residual combustion are negligible and only advancing-front combustion need be considered. Such burns would have an emission factor of 50.

RATE OF SPREAD

Pine needle and low-brush fuel types are similar in fuel makeup and arrangement. Fire behavior will, therefore, be considered the same for identical fuel moisture and wind conditions.

The best estimate of rate of fire spread in this fuel type was calculated with the Rothermel spread model (Rothermel 1972). Rates of fire spread are shown in table VI-F-8 (page 112).

As in the grass model, rate of fire spread can be predicted by knowing only midflame windspeed and fine fuel moisture (1-hour timelag) values. This windspeed can be estimated by obtaining a value from a 20-foot, open-tower installation at a nearby fire-danger rating station and dividing that value by 4. Fine fuel moisture can be read from table VI-F-3 (page 107) as a function of only relative humidity. Rate of spread in feet per minute is read from table VI-F-8 (page 112). If desired, the rate of spread in feet per minute can be converted to miles per hour:

$$\text{mph} = \frac{\text{feet per minute}}{88}$$

PALMETTO-GALLBERRY WITH PINE OVERSTORY FUEL TYPE

DESCRIPTION

The vegetation commonly referred to by southern forest fire control personnel as the palmetto-gallberry fuel type can vary widely in amount of vegetation and plant composition throughout its range. Saw-palmetto (*Serenoa repens* [Bartr.] Small) is native to the Lower Coastal Plain, extending south from Charleston, South Carolina, into the whole of Florida and west into southeastern Louisiana (Hilmon 1968).

The gallberry (*Ilex glabra* [L.] Gray) range overlaps the palmetto range, but is considerably more extensive, stretching from Nova Scotia to Louisiana (Gleason 1968). Within the fuel type both shrub species are generally associated and predominate, although in south Florida the gallberry may be totally absent.

Other shrub associates include blueberry (*Vaccinium myrsinites* Lam.), dwarf pawpaw (*Asimina parviflora* [Michx.] Dunal.), titi (*Cyrilla racemiflora* L.), dwarf candleberry (*Myrica cerifera* var. *pumila* Michx.), tar-flower (*Befaria racemosa* Vent.), running oak (*Quercus pumila* Walter.), huckleberry (*Gaylussacia* spp.), fetterbush (*Lyonia lucida* [Lam.] K. Koch), pepperbush (*Clethra acuminata* var. *tomentosa* [Lam.] Michx.), etc.

The herbaceous stratum is made up primarily of grasses and dominated by wiregrass and broom-sedge.

The genera *Aristida*, *Andropogon*, *Panicum*, and *Rhynchospora* comprise a major portion of the herbaceous weight on sites that are frequently burned. In parts of South Carolina, brackenfern

Figure 16. — Palmetto-gallberry fuel type.

(*Pteridium aquilinum* [L.] Kuhn.) is the predominant herb, while tropical shrubs predominate in the south Florida Everglades.

This fuel type is usually found under an overstory of loblolly, slash, or longleaf pine, and considerable quantities of pine needles are mixed with dead grass and other vegetative debris in the ground litter. All estimates of fuel buildup for this type assume the presence of a pine overstory.

FUEL LOADING

The palmetto-gallberry type has two levels of fuel: (1) the understory living vegetation and standing or logged debris and (2) dead material on the forest floor. Separate computations must be made for each level.

Understory

Weight of understory vegetation is related to time since last disturbance (age of rough) and vegetative height. Table VI-F-9 (page 113) shows weights of understory vegetation; but to use it, average height of representative understory vegetation must first be estimated. If, for example, understory height averages 4 feet and age of rough is 3 years, the weight of understory material would be 4.6 tons per acre.

Available Litter Fuel Estimate

The litter buildup in a palmetto-gallberry fuel type is primarily influenced by the pine overstory and should be predicted from table VI-F-5 (page 109) or VI-F-6 (page 110) using basal area of the stand and age of rough as inputs.

Data from prescription-burned experimental plots containing aerial fuel in addition to pine litter were analyzed for fuel consumption. Differences between backing and low-intensity heading fires were not great, so all the data were combined. Data needed to estimate available fuel are:

1. Total standing understory vegetation (table VI-F-9, page 113)
2. Total litter fuel (table VI-F-5, page 109) or VI-F-6 (page 110)
3. Moisture content of the total litter layer from a worksheet (table 9) as shown in this Chapter.

Tables 7 and 8 are used to determine the changes in moisture content of the total litter from normal drying, or from wetting by rain. Their use is explained on pages 31 and 32.

The amount of available fuel consumed from the entire understory fuel bed (includes litter) is presented in table VI-F-10 (page 114). This table has six sections (10, 20, 40, 80, 120, and 160 percent) that represent the range of litter fuel moisture that would be expected when prescribed burning would be considered. The moisture interval is smaller at the lower moisture contents because the change in available fuel consumed is greatest at these lower moisture contents. Should the predicted moisture level not correspond to one of the moisture content sections listed (e.g., 50 percent instead of 40 or 80 percent), choose the section with the closest value (the 40-percent moisture content in this case). Limitations on the accuracy of estimates in the palmetto-gallberry fuel type depend primarily upon the accuracy of the litter and moisture content estimates. These estimates should, therefore, be made with care.

EMISSION FACTOR

The calculated emission factors from experimental field burns in Georgia ranged from 11.8 (pounds of particulate matter per ton of consumed fuel) to 41.2. Based on these field experiments, an advancing-front particulate matter emission factor (EF_A) of 25 pounds per ton of palmetto-gallberry fuel burned is suggested for use with backing fires. This value is believed to be less than emissions from pine needle litter because fuel bulk density is lower and combustion is, therefore, more efficient. No measurements were made for heading fires in the type; if heading fires in 1- or 2-year-old roughs are contemplated, the same emission factor of 25 should be used. Emissions from the residual combustion stage are considered negligible for heading fires in young roughs.

Heading fires in older roughs would evolve appreciable emissions during residual combustion in the litter layer; a much higher emission factor for this stage of combustion (EF_R) of 125 pounds of particulate matter per ton of palmetto-gallberry fuel consumed is suggested for use. The emission rate (ER_{A+R}) for the convective-lift fire phase of older rough heading fires is:

$$ER_{A+R} = ER_A + ER_R$$

RATE OF SPREAD

Rate of fire spread in palmetto-gallberry fuel was estimated from measures of fuel and fire behavior in this fuel type. Hough and Albini (1976) describe the measurement and analytical procedures used to derive the rate-of-spread equations. If windspeed at midflame height and fine fuel moisture (table VI-F-3, page 107) are known, fire spread rate can be read directly from table VI-F-11, page 115. For backing fires, assume the windspeed is zero.

Figure 17. — Emissions from the residual combustion phase in backing fires, and in heading fires with rough less than 2 years old, are negligible for the palmetto-gallberry fuel type.

The proper value to be used for midflame windspeed in table VI-F-11 (page 115) can be estimated by using values taken from a 20-foot, open-tower installation at the nearest fire-danger station and dividing that value by 4. If desired, the rate of spread can be converted to miles per hour:

$$\text{mph} = \frac{\text{feet per minute}}{88}$$

PINE LOGGING DEBRIS FUEL TYPE

DESCRIPTION

This fuel type is made up of tree parts left on an area following logging, plus a very disturbed natural understory fuel. The debris consists mostly of the upper portion of the central bole, tree branches, and needles. Other residue could include unmerchantable "whip" trees and hardwoods.

Logging debris can be burned in one of two ways. The debris can be piled to permit consumption of all small and much of the larger residue elements (branches and tops exceeding 1 inch in diameter), or it can be left scattered where the individual trees were felled to be consumed by a broadcast burn of the area. The latter type burn usually consumes only residue less than 1 inch in diameter.

We have insufficient data to account for differences in emissions from piled debris because piling methods and pile conditions can vary widely. Therefore, this Guidebook will *not* have a section for piled debris. Further research in this fuel type is in progress. The Guidebook does, however, give a procedure for predicting particulate matter emission rate and heat yield from the burning of broadcast debris. This procedure is based upon very scant observations and little experimental evidence.

FUEL LOADING

Residue weight may be estimated by several methods. The traditional procedure is to gather all material from many small sample plots, separate by size class, dry, and express weight on a unit area

Figure 18. — Unpiled pine logging debris fuel type.

basis. More recent estimating procedures are the line intercept method (Van Wagner 1968) and the planar intercept method (Brown 1971). These methods are useful where the slash from several species of trees is present. The techniques do not require the collection of material, but considerable field time and effort are still needed.

A quicker and more economical method is to relate the quantity of crown residue left on the ground to average diameter at breast height (d.b.h.), basal area, and volume in the stand that was cut. Two studies have been completed on amount of dry residue left on the forest floor following standard logging of two major southern species. One involves loblolly pine residue (Taras and Clark 1974) and the other slash pine residue (data on file at the Southern Forest Fire Laboratory).

Logging debris that has been left undisturbed and is scattered over the entire logged area is generally burned with some form of heading fire. Such fires consume only fuel less than 1 inch in diameter. Table VI-F-12 (page 116) depicts the amount of residue, in tons per cord cut (logged), that would generally be consumed when broadcast burning a logged area. Note that the average d.b.h. of the logged stand has some effect on the amount of residue that will be left on the ground. If d.b.h. of the stand averaged 8 inches and the species was loblolly, for every cord of timber cut there is 0.15 ton of available residue on the ground. If average stand d.b.h. was 11 inches, there is 0.12 ton of available residue per cord. Total residue on an area is the product of tons of residue per cord cut (from table VI-F-12, page 116) and total cords cut on the area. By dividing this answer by the number of acres in the logged area, the residue weight is expressed in tons per acre.

SPECIAL RULE OF THUMB

Debris that has been left broadcast over a logged area is usually burned in one of two ways. It may be head fired from its upwind side toward the downwind side, which is usually backfired in advance. Primary fuel consumption is from the movement of the heading fire, and length of the active burning front for computing heat release rate (HRR) is easily ascertained.

Ring firing may be used instead. This technique usually begins with the firing of the downwind side of the area, followed by the firing of the two flanks simultaneously. Finally, the upwind side is fired to totally encircle the area with fire. Fire movement is toward the center of the area.

Determining the length of active fire for a ring-fired area poses problems. When there is wind movement, the heading portion of the fire is obviously active. But so are the flanks, and as the fire progresses all sides are shrinking in length. For purposes of this Guidebook, the movement of the backing fire will be ignored, even though this side of the fire is obviously contributing some heat and particulate matter to the reaction. Where ring firing is used and there is no wind, all fired sides probably move toward the center at an equal rate.

A rule of thumb has been developed for estimating a length-of-fired line value for computing HRR in Chapter VI. The procedure was developed in an attempt to make an allowance for the fire activity on the burning flanks. To complete the procedure, a scale map of the area to be burned is needed. On the map, draw a line perpendicular to the expected or planned wind direction along the upwind edge of the area to the extremities (fig. 19, line a to b). Draw a second line (c to d) along the downwind edge of the area and connect these two lines with diagonals from the extremities of each. Where the diagonals intersect, label the point (x). Length of fired line for computation of HRR is the sum of scaled lines a to x and b to x. This is the entry needed for Chapter VI.

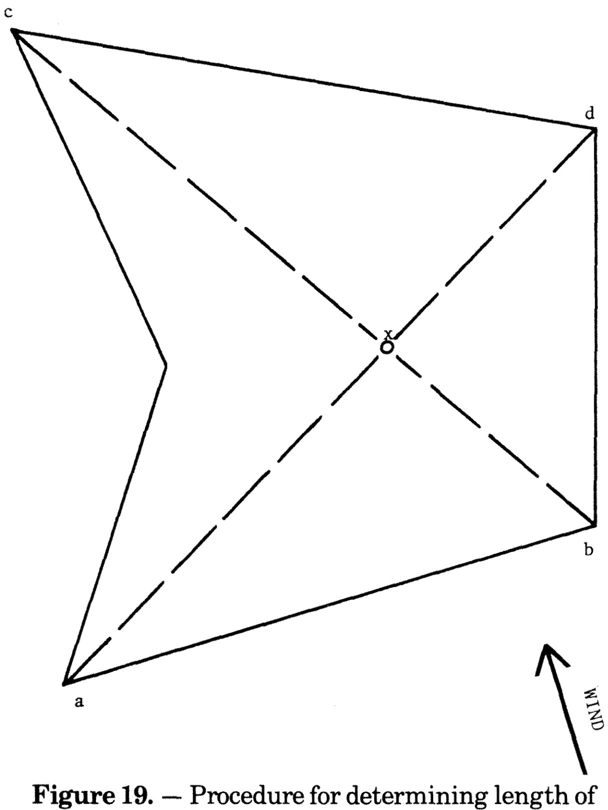


Figure 19. — Procedure for determining length of fired line for heat release rate (HRR) calculations for ring fires in the logging debris fuel type.

EMISSION FACTOR

Emissions from fires moving through unpiled logging debris occur in two phases—the convective-lift phase and the no-convective-lift phase. Emissions during the convective-lift phase are from both the advancing-front combustion stage and the residual combustion stage behind the advancing front.

Six to 18 months usually elapse between logging and burning. During this time much of the accumulated litter breaks down, leaving primarily the logged litter layer of residue over the soil. Upon firing, 75 percent ($y_A = 0.75$) of the available fuel is estimated to be consumed in the advancing-front combustion stage, leaving only 25 percent ($y_R = 0.25$) to be consumed during the residual combustion stage. These proportions are based on data taken from sample areas of debris burned in the southern Piedmont of Georgia near Macon.

Determination of representative emission factors for this fuel type must be partially subjective due to the limited data currently available. Results from the limited fuel beds burned in the laboratory indicate emission factors much below values expected, compared with values for the seemingly similar pine needle litter and palmetto-gallberry fuel types. The difference between expected results and laboratory results can be explained only by hypotheses that: (1) aerial distribution of pine logging debris may result in flame interactions that reduce particulate matter emissions, and (2) laboratory fuel beds used may not have been representative of area-wide fuel arrangements found in actual field situations for pine logging debris.

Laboratory-derived particulate matter EF values of 5 and 75 pounds per ton of fuel for pine logging debris in the advancing-front and residual combustion stages, respectively, must be regarded as tentative until further laboratory and field work is completed. We are suggesting, therefore, that 35 and 180 pounds per ton of fuel be used for the advancing-front and residual combustion stages, respectively. These more conservative EF values for unpiled pine logging debris are drawn from comparisons with other fuel types, but allow for possible interactions indicated by limited laboratory work to date. Use of these values will minimize the risk of unwanted environmental consequences until research is completed.

When computing the emission rate to be used for the convective-lift fire phase for heading (or ring) fires (ER_{A+R}) in this fuel type, the simultaneous activity of both stages of combustion are accountable. The equation is as follows:

$$ER_{A+R} = ER_A + ER_R$$

RATE OF SPREAD

Observations of fire spread rate in this fuel type are limited. Until better data are available, the rate-of-spread curves in NFDRS Model C (Deeming and others 1972) fuel, with modifications (table VI-F-13, page 117), should be used.

The only input variables needed to read rate of spread from table VI-F-13 (page 117) are fine fuel moisture (from table VI-F-3, page 107) and midflame windspeed. The midflame windspeed should be obtained by taking the value at the nearest fire-danger rating station having an anemometer mounted on a 20-foot tower and dividing that value by 2. A factor of 2 is used rather than 4 because of the effect of removing the overstory. If desired, rate of spread can be converted to miles per hour:

$$\text{mph} = \frac{\text{feet per minute}}{88}$$

CONCLUSIONS

Although many voids in knowledge exist, we have presented useful new information on rates of spread and available fuel. These data have been badly needed in the fuel types covered.

In general, practices and fuel conditions that minimize particulate matter production from the burning of forest fuel are:

1. Favoring backing fires where possible
2. Cutting to low stumps and felling dead snags
3. Burning when fuel moisture is low
4. Minimizing amount of logging debris through utilization to small top diameters
5. Burning scattered logging debris rather than piled debris.

LITERATURE CITED

Brown, James K.

1971. A planar intersect method for sampling fuel volume and surface area. For Sci. 17(1):96-102.

Brown, Arthur A., and Kenneth P. Davis

1973. Combustion of forest fuels, p. 163. *In* Forest fire: control and use. 2d ed. McGraw-Hill Book Co., Inc., New York.

Deeming, John E., James W. Lancaster, Michael A. Fosberg, and others

1972. National fire-danger rating system. USDA For. Serv. Res. Pap. RM-84, 165 p. Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo.

Gleason, Henry A.

1968. Illustrated flora of the northeastern United States and adjacent Canada. 2d ed., vol. 2, 655 p. Hafner Publ. Co., Inc.,New York.

Grelen, H. E.

1962. Succession on cleared sandhills in northwest Florida. Am. Midl. Nat. 67:36-44.

Helvey, J.D.

1964. Rainfall interception by hardwood forest litter in the southern Appalachians. USDA For. Serv. Res. Pap. SE-8, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

Hilmon, J. B.

1968. Autecology of saw palmetto (*Serenoa repens* [Bartr.] Small). Ph.D. dissertation, 190 p. Dep. Botany, Duke Univ., Durham, N.C.

Hough, W. A.

1968. Fuel consumption and fire behavior of hazard reduction burns. USDA For. Serv. Res. Pap. SE-36, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Hough, Walter A.

In press. Estimating available fuel weight consumed by prescribed fires in the South. USDA For. Serv. Res. Pap. Southeast. For. Exp. Stn., Asheville, N.C.

Hough, Walter A., and Frank A. Albini

In press. Predicting fire behavior in palmetto-gallberry fuel complexes. USDA For. Serv. Res. Pap. Southeast. For. Exp. Stn., Asheville, N.C.

McNab, W. Henry, and M. Boyd Edwards, Jr.

1976. Estimating forest fuel buildup. For. Farmer 35(5):6-7.

Metz, Louis J.

1958. Moisture held in pine litter. J. For. 56(1):36.

Rothermel, Richard C.

1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115, 40 p. Intermountain For. & Range Exp. Stn., Ogden, Utah.

Swank, Wayne T., Norbert B. Goebel, and Junior D. Helvey

1972. Interception loss in loblolly pine stands of the South Carolina piedmont. J. Soil Water Conserv. 27:160-164.

Taras, Michael A., and Alexander Clark III

1974. Aboveground biomass of loblolly pine in a natural, unevenaged sawtimber stand in central Alabama. TAPPI For. Biol. Conf:107-116.

Van Wagner, C. E.

1968. The line intersect method of forest fuel sampling. For. Sci. 14(1):20-26.

Van Wagner, C. E.

1970. An index to estimate the current moisture content of the forest floor. Dep. Fisheries For., Can. For.Serv. Publ. No. 1288, 23 p., Ottawa, Ontario.

CHAPTER V

SMOKE TRANSPORT AND DISPERSION

by

James A. Pharo, Research Meteorologist
Leonidas G. Lavdas, Research Meteorologist
Philip M. Bailey, Physical Science Technician
Southern Forest Fire Laboratory
Southeastern Forest Experiment Station
USDA Forest Service
Macon, Georgia

The purposes of this Chapter are:

To outline phenomena affecting transport and dispersion of smoke

To introduce concepts of air pollution climatology important to scheduling burning operations when the probability of good smoke transport and dispersion is greatest

To explain the bases we used to select and adapt mathematical models for predicting concentrations of smoke from forestry burning.

The models described were adapted only for common forestry burning situations in the South, but with further adaptation they can be applied elsewhere.

PHENOMENA AFFECTING SMOKE TRANSPORT AND DISPERSION

It has been difficult to achieve a proper balance between too much and too little information for the wide spectrum of readers expected to use this Guidebook. For those who desire more background on basic weather variables, we suggest a text like *Fire Weather* (Schroeder and Buck 1970).

ATMOSPHERIC STABILITY

The definition of atmospheric stability as it affects smoke dispersion is the degree to which the atmosphere resists turbulence and vertical motion. In this discussion it is convenient to consider portions of air as parcels. Parcels of air do not have strict boundaries (as if encased in a wrapper); they tend to mix and take on the characteristics of their surrounding environment.

Consider a parcel of air heated to a certain temperature at the Earth's surface. The more unstable the atmosphere, the more readily the less dense, heated air parcel will rise by convection. Similarly, a more dense, cooled parcel of air will descend more rapidly under unstable conditions. When a parcel of air is heated by a forest fire and carries smoke with it, the rate and height of its ascent are essential to our calculations of subsequent dispersion.

Atmospheric stability is more properly defined by air temperature changes with height over a specific location. The adiabatic lapse rate, a temperature decrease of 1° C per 100 meters (5.5° F per 1,000 feet), defines a neutral atmosphere and is the basic reference for other stability classifications. The atmosphere is unstable if its lapse rate is greater than neutral, and stable if less. Neutral conditions can usually be found below cloud bases during cloudy and windy conditions. An unstable atmosphere usually occurs in early afternoon on clear days with light winds. Stable conditions usually occur at night when the air is clear and the winds are light.

TEMPERATURE INVERSIONS

An inversion layer is a special case of the temperature-height relationship just discussed. Temperature in this layer increases instead of decreases with height. When our previously considered heated parcel of air encounters an inversion layer it soon stops rising. Because it cools quickly as it rises, the parcel reaches the same temperature as the very stable surrounding air. An inversion can thus be thought of as a *lid* on a smoke column.

Forestry smoke managers should be careful to avoid low and intermediate level inversions in order to keep from having such a lid imposed upon the smoke from their burns. If the inversion layer

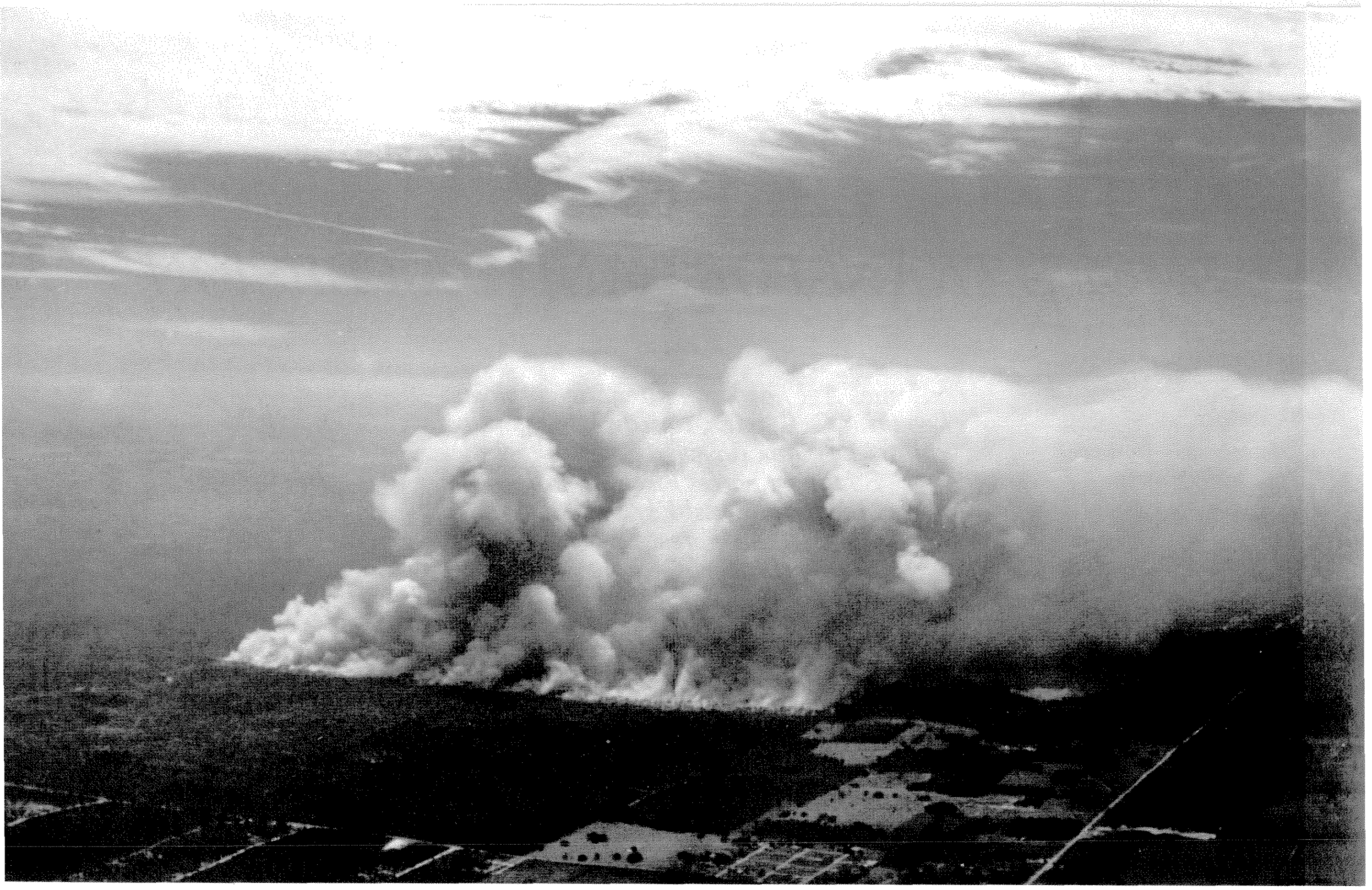


Figure 20. — Major factors affecting smoke transport and dispersion include vertical plume rise, horizontal movement on an azimuth determined by the transport wind direction, and dispersion by physical forces such as atmospheric mixing.

is very weak (i.e., not very thick in the vertical dimension and temperature increase with height is not great), the heated air from a fire can sometimes penetrate this layer. When it does, the smoke then has a better chance for dispersion, but there is often a surprising change in fire behavior. Smoke from the no-convective-lift fire phase will not penetrate the inversion lid. It is, therefore, best to avoid prescribed burning when low inversion layers affecting the fire are predicted.

MIXING HEIGHT

The temperature inversion is one kind of lid that traps smoke beneath it. Stable layers of less than inversion intensity are another form of lid. These lids determine mixing height. Mixing height is the atmospheric limit above which vigorous vertical mixing does not take place. It is a height at which airmass stability is sufficient in strength and depth to inhibit further upward transport of smoke.

Mixing height represents the top of the atmospheric volume available for dispersion. High mixing heights imply that large volumes of air are available for smoke dispersion. Thus, with higher mixing heights, smoke concentrations will be less—especially at long distances from the fire. Mixing heights of less than 500 meters are often associated with air pollution episodes.

TRANSPORT WINDSPEED

You have probably seen smoke columns that go up to one of the lids just described and then just smear out in all directions. This occurs when there is little or no transport wind. The smoke column that bends or shears is encountering wind as it rises.

Windspeeds usually increase with height, except where funneling takes place near the ground (as through a mountain saddle or opening in the forest). Transport windspeed is the arithmetic average of all windspeeds within the mixing layer, including surface windspeed. Smoke concentrations usually decrease as transport windspeeds increase. Transport windspeeds of less than 4 meters per second are indicators of stagnant conditions which often result in air pollution episodes.

TRANSPORT WIND DIRECTION

Wind direction usually veers (changes to the right) with height. Veering with height is important in determining where the smoke will go. The

change in wind direction with height is due to friction that causes ground-level winds to be deflected to the left in the Northern Hemisphere. As the height above the Earth increases, there is a decrease in friction. The rougher the surface, the greater the change. Veering with height over even-aged pine stands on relatively level terrain is between 15 and 20 degrees in the first kilometer (3,281 feet) of height. Over markedly uneven-aged pine stands in rough terrain, it is as much as 40 to 45 degrees. Changes in wind direction with height tend to be more pronounced at night than during the day because vertical motion is usually diminished at night.

LOCAL-SCALE SYSTEMS

Local-scale (sometimes called small-scale) systems are associated with fixed geographic features and do not travel from one location to another like high- and low-pressure systems. They often develop, persist, and dissipate in one small locale. Land and sea breezes are examples of this phenomenon. These breezes change stability, windspeed, and wind direction.

Along coastlines on clear, summer days when early morning winds are light, onshore winds frequently develop by midafternoon—penetrating inland. This sea breeze effect is due to land surfaces being warmer than the sea surface. Similar circulations, much weaker and less widespread, often occur along margins of lesser water bodies, and even open fields, that differ significantly in temperature from adjoining land surfaces.

Mountain-valley or slope-valley wind is another example of a local weather phenomenon that can affect smoke transport and dispersion. On clear nights, high slopes cool by radiation; the air adjacent to them becomes colder and denser, and drains into the valley. The reverse of this drainage flow may occur during the day.

These local-scale systems are important because they directly affect the dispersion of smoke by causing abrupt changes in local atmospheric stability and can influence the direction in which smoke will be transported. They are somewhat predictable—often site dependent.

OBTAINING CURRENT AND FORECAST WEATHER FOR APPLICATION

Limits on values for the phenomena covered in the preceding section need to be specified in a fire prescription, then checked against current and forecast weather for a specific locale, and for specific times.

National Weather Service Forecast Offices can supply the following information in spot forecasts:

Mixing height (also referred to as height of the mixing layer)

Surface windspeed (in the open at a height of 10 meters)

Transport windspeed

Transport wind direction.

Both transport windspeeds and mixing heights are reported in metric units. The probable transport wind velocity (direction and speed) is usually the vector-sum of reported or forecast winds through the mixing height.

As of this writing, stability expressed in the Pasquill (1975) stability classes used in Chapter VI is not available through the National Weather Service. These values may eventually be provided, but until they are the smoke manager must predict the class from reported *cloud cover* and *cloud height* plus angle of the sun. A predicting method is provided in Table 11.

POLLUTION CLIMATOLOGY

Forestry smoke managers responsible for a large number of planned burns are urged in Chapter VI to develop schedules based upon the total number of days with good probability of satisfactory smoke transport and dispersion, as well as other burn objectives. To do this requires an understanding of the climatology of pollution and a knowledge of available sources of appropriate climatologies. This leads us to consider again the phenomena affecting transport and dispersion discussed earlier.

Climate, the synthesis of these conditions over a long time, should be used in formulating long-range prescribed burning plans. Climatic conditions to be considered in prescription burning plans include stagnation, mixing, windspeed, and wind direction frequencies.

To avoid high concentrations of smoke in sensitive areas, burning often has to be done when the

Table 11. — Stability estimating method [1/]

Surface windspeed (mph)	DAY									NIGHT	
	Clear or 50% or less cloud cover w/ low & mid clouds; or any high clouds			More than 50% low and mid clouds			More than 50% low clouds			50% or more cloud cover w/low and mid clouds or high overcast	Clear or less than 50% cloud cover w/ low and middle clouds
	6-foot vertical standard shadow length (in feet)										
	Less than 3.5	3.5 to 8.5	Greater than 8.5	Less than 3.5	3.5 to 8.5	Greater than 8.5	Less than 3.5	3.5 to 8.5	Greater than 8.5		
Less than 4	A [3/]	A-B	B	A-B	B	D	B	D	D	DO NOT BURN [2/]	DO NOT BURN [2/]
4 - 7	A-B	B	C	B	C	D	C	D	D	E	F
8 - 10	B	B-C	C	B-C	C	D	C	D	D	D	E
11 - 14	C	C-D	D	C-D	D	D	D	D	D	D	D
More than 14	C	D	D	D	D	D	D	D	D	D	D

1/ After Pasquill (1975), with insolation estimates incorporating shadow length or cloud cover after Lavdas (1976).
2/ Burns will be delayed in Decision-Logic Stage No. 1, Chapter VI.
3/ Shaded areas indicate categories for which typical cases are not presented in Chapter VI.

How to use table:

1. Locate main column head for day or night. Night applies from 1 hour before sunset to 1 hour after sunrise.
2. Locate subcolumn head for cloud cover.
3. If for day situation, locate sub-subcolumn head for 6-foot vertical standard shadow length.
4. Locate row for surface windspeed.
5. In row and under column, read stability class category.

Example: Day with more than 50 percent low and mid clouds and shadow length less than 3.5 feet with windspeed 8 to 10 mph. Read stability category B-C.

wind is blowing in a particular direction. Forestry smoke managers can determine the probability that the wind will be blowing in the proper direction on a given day from summaries of prevailing seasonal wind directions.

Needed climatological information may be found in the literature cited in this section. The Climatic Atlas of the United States (available from the National Climatic Center, Federal Building, Asheville, North Carolina 28801) is another comprehensive source. This publication gives monthly and seasonal averages and totals for most of the phenomena affecting transport and dispersion. Airport summaries of windspeed and direction frequencies are available from the National Climatic Center as well.

Two primary factors that inhibit atmospheric dispersion are light winds and stable atmospheres. When these persist, stagnation occurs. High-pressure systems, or anticyclones, exhibit both of these characteristics. Korshover (1971) used 35 years of upper air observations to determine the relative occurrence of stagnant anticyclones. He found that stagnant conditions in the Southeast occur most frequently during late summer and fall. The maximum number of stagnant episodes lasting 4 days or more occurred in north Georgia and in western North and South Carolina.

Stagnant anticyclones are not the only systems that result in poor dispersion conditions. Dilution capacity of the atmosphere may be poor during other meteorological patterns, such as when inversions persist. Hosler (1961) reported the frequency of low-level (less than 500 feet) inversions over the Continental United States during a 2-year period. His findings agree well with Korshover's (1971)—inversions causing poor dispersion patterns in the Southeastern United States occur most frequently in the fall, but may occur in any season.

Holzworth (1972), in his analysis of 5 years of National Weather Service data, presented mixing heights, windspeeds, and the resulting potential for urban air pollution throughout the contiguous United States. His generalizations may be applied to rural atmospheres.

MATHEMATICAL MODELS

Different assumptions about governing processes and behavior have resulted in many different models for calculating dispersion. Some are different merely because of their intended application. Additional work will undoubtedly yield yet a wider variety from which to choose. In the discussions that follow, we will address the criteria we used for selecting a dispersion model—as well as the related approaches used in the decision logic in Chapter VI. We will also cover modifications imposed upon selected approaches, but will leave full development and defense of previously published equations to cited sources.

Three general criteria were applied in selecting and adapting the model:

1. Predictions close to the burn are the most critical, and the model must accurately reflect source and atmospheric variables.

2. The model must be widely accepted by scientists in regulatory agencies.

3. The model must permit either computer or desk-top calculations.

In order to provide a practical predictive method for smoke concentrations at downwind locations, it has been necessary to assign fixed values for some factors. In Chapter IV two separate fire phases are described: the *convective-lift* and the *no-convective-lift fire phases.* While smoke entrainment will gradually increase then decline in the convective-lift phase, use of a steady state is believed to be realistic in order to make calculations manageable. In the no-convective-lift phase, emissions will gradually decline; but again, using a steady-state condition is necessary if anything but extremely complex equations calling for automatic data processing are to be applied. Similar steady-state compromises are applied in the final transport and dispersion model to be introduced in this section for use in Chapter VI. In addition to these practical considerations, current knowledge does not justify more sensitive, time-dependent adjustments at this time.

PLUME RISE

The height that the center of the smoke plume attains is called plume rise. During the convective-lift phase of combustion, heat released by the fire causes convective lift of emissions from the fire in a definite column. As this heat diminishes, the plume loses its columnar shape to a point where lift of emissions is mostly a result of vertical atmospheric mixing alone. Thus, while atmospheric stability is an important variable at all times, heat release rate, explained in Chapter IV, will be employed only for the convective-lift phase. Winds impinging upon the column during the convective-lift phase tend to bend or shear it, restricting the total possible plume rise. Plume rise, therefore, is a function of heat release rate, atmospheric stability, and transport windspeed. Inversions will also limit plume rise and are accounted for by stability. Mixing height becomes important after the initial convective lift, and is incorporated in the final dispersion model.

In discussions with Dr. Gary A. Briggs of the NOAA Oak Ridge Laboratory, we elected to adapt the plume rise relations he developed for stack emissions handled as point sources. Briggs' (1969, 1971, 1972) plume rise relationships fit satisfactorily for prescribed fires when his term Q_H is expressed as the total rate of heat release from the entire length of fired line, as determined by relationships explained in Chapter IV. Relationships were examined for stability classes A through F (Pasquill 1975). Equations (1) through (4) are used in calculating ultimate plume height, in which:

H = height (in meters)

Q_H = total heat release (in calories per second)

u = transport windspeed (in meters per second).

For stability classes A through D, and Q_H less than 1.40×10^6 cal/sec:

$$H = 0.0101\, Q_H^{\,3/4}\, u^{-1} \qquad (1)$$

For stability classes A through D, and Q_H greater than 1.40×10^6 cal/sec:

$$H = 0.0847\, Q_H^{\,3/5}\, u^{-1} \qquad (2)$$

For stability class E and all values of Q_H (temperature increase with height of 1°C per 100 m assumed):

$$H = 0.917\, Q_H^{\,1/3}\, u^{-1/3} \qquad (3)$$

For stability class F and all values of Q_H (temperature increase with height of 2.5°C per 100m assumed):

$$H = 0.761\, Q_H^{\,1/3}\, u^{-1/3} \qquad (4)$$

Equations (1) through (4) are used to calculate plume rise while the smoke rises for some distance as it travels downwind. Often ultimate height is not reached for several kilometers downwind. This distance is not affected by transport windspeed. Briggs' (1969) ultimate height for a 1 megacalorie per second source is attained about 480 meters (0.3 mile) downwind. From Briggs' work, downwind distances to ultimate heights for sources releasing heat at different rates under stability classes A through D compare as follows:

Heat release (Megacal/sec)	**Approximate downwind distances to ultimate heights (Miles)**
1	0.3
10	0.8
100	2.0

It can be shown that at one-third the downwind distance to ultimate height, one-half the ultimate height is consistently attained. For example, a 10 megacalorie per second fire with an ultimate plume rise limited to 250 meters will have attained a height of 125 meters at 0.27 mile downwind (i.e., 1/3 x 0.8 mile).

When Briggs' (1969) equation (4.30) is applied, most southern prescribed fires are shown to be unable to penetrate a modest inversion of 1° C at 100-meter elevations or higher.

Now we have a means to express the total height of the plume. That portion of the smoke observed to remain unentrained and traveling along the ground still remains to be accounted for. This phenomenon is experienced even during the hottest portion of the convective-lift phase in southern prescribed fires. Additional research is needed, but observations of the phenomenon on three experimental fires were used to arrive at a ratio of 60-rise to 40-no-rise for the amount left unentrained. This ratio was borne only by observations on a fourth experimental fire.

The 60:40 ratio has thus been suggested for a limited number of both heading and backing fires. When heat release (HR, the heat released per unit of fired-line length, rather than the total heat release rate (HRR), or Q_H) is increased, the ratio can logically be expected to increase toward 100:0, provided stability and transport windspeed remain unchanged. For example, a campfire can be seen to lift all emissions by convection so long as its heat causes a *draw* from all portions of the fire. But the same fire, while still maintaining a convection column, will in time cease to draw smoke from its outer portions. Smoke from these portions will then tend to drift free from convective lift. This is essentially what takes place in most southern prescribed fires covered in the logic of Chapter VI. It seems likely additional research will lead to adjustments in the 60:40 ratio.

In working with plume rise under unstable atmospheric conditions, the effect of vertical wind eddies that temporarily bring high smoke concentrations aloft closer to the ground have been evaluated. The largest vertical eddies occur when instability is greatest. Eddy sizes decrease as conditions become more nearly stable, and the plume rise fluctuations become less significant. These conditions have been found to be important to dispersion calculations for emissions from cool sources like elevated smoke stacks, but they have not been observed in our experimental fires in the Southeast.

To summarize, two expressions have been introduced. These are the factor H for ultimate plume height, and the coefficient 0.6 for the amount of smoke entrained in the convection column of the convective-lift fire phase. Both will be noted as adaptations in the dispersion model to be discussed in following subsections.

SELECTION OF A DISPERSION MODEL

Forest managers have been exposed to the "tank concept" and to applications of a "box model" of dispersion. These names are sometimes incorrectly described as interchangeable. Before selecting any more complex model, it was thus necessary to assess possible adaptations of these two relatively simple approaches.

The "tank concept" is a convenient way of thinking about a certain atmosphere's ability to "absorb" a specified level of air pollutants. The atmosphere, of whatever dimension, is thought of as a container with imaginary "walls" (such as mountains, but sometimes only arbitrary or political boundaries) and a "lid" (such as imposed by an inversion or by the mixing height). It is assumed that smoke is distributed evenly, and that emissions can be accommodated until smoke concentrations reach an accepted maximum for the "tank" as a whole. Unfortunately for a management use of this concept, however convenient it may be in gaining an initial grasp of air pollution problems, the real world of smoke transport and dispersion does not operate nearly so simply! Within the "tank," emissions from each source flow along an axis determined by the transport wind direction. Initial horizontal and vertical diffusion (dispersion) is defined by physical laws that do not result in uniform distributions of pollutant concentrations, even when the "tank" has real walls such as a valley or mountain canyon. The result is that along the path of the plume initial smoke concentrations will be greater than in the "tank" as a whole (a very undemocratic consequence for individuals along the plume's path if they are depending upon administrators of the "tank" to assure them their equal share of pure air).

The term "box model" differs from the "tank concept" in that dispersion takes place along an axis determined by transport wind direction. Distribution, however, is considered to be uniform. This model has gained acceptance through application to dispersion problems in the Willamette Valley of Oregon (Reiquam 1970). A derivation labeled the "smoke-volume model" has been suggested by Williams (1974) for application to prescribed fires. This variant differs from the box model in that the plume is restricted by formulas based upon measured heights and widths of experimental fires. The principal advantage of uniform distribution models is the ease with which calculations for different downwind distances can be accomplished. A potential for solution of long-range transport problems has been identified (Pasquill 1972). The chief disadvantage, however, is that because plume rise is not accounted for, the predicted ground-level concentrations due to a uniform vertical distribution are not valid for locations within the first 100 kilometers (62 miles) of sources.

Wide acceptance has been gained for application of the Gaussian distribution to dispersion modeling. A statistical tool, the Gaussian distribution permits a general description of smoke plume dispersion over time. There have been numerous independent validations in both laboratory and field experiments (Hay and Pasquill 1957; Cramer, Record, and Vaughan 1958; and Barad and Haugen 1959). A workbook, published by the U.S. Environmental Protection Agency (Turner 1970), enjoys widespread application by scientists working on dispersion. This approach employs Gaussian distribution, as well as a synthesis of the work of other accepted authorities. Methods of the Turner Workbook (1970) have thus been selected for use in this Guidebook.

ADAPTATION OF THE TURNER WORKBOOK METHODS TO A MODEL FOR MANAGING SMOKE FROM PRESCRIBED FIRE IN THE SOUTH

Our initial adaptation of the Turner Workbook is straightforward, with Equation (5) being the model used. Combinations of terms and derivations are after Turner (1970), except as adaptations are explained in the list of variables and coefficients (table 12).

$$\chi = \frac{q}{\sqrt{2\pi}\, u\sigma_z} \left\{ 1.6 \sum_{N=1}^{N=3} \exp\left[-0.5\left(\frac{H}{\sigma_z}\right)^2\right] + 1.2 \exp\left[-0.5\left(\frac{H}{\sigma_z}\right)^2\right] + 1.2 \sum_{N=1}^{N=3} \left(\exp\left[-0.5\left(\frac{H - 2NM}{\sigma_z}\right)^2\right] + \exp\left[-0.5\left(\frac{H + 2NM}{\sigma_z}\right)^2\right]\right)\right\} \int_{-L/2\sigma_y}^{L/2\sigma_y} \frac{1}{\sqrt{2\pi}} \exp\left[-0.5\,(y/\sigma_y)^2\right] d(y/\sigma_y) \tag{5}$$

Page 446 of 644

Table 12. — **Variables and adaptive coefficients used in Equation (5). Other coefficients are from Turner (1970).**

Variable or coefficient	Definition and discussion	Units
χ	Centerline, ground-level concentration	micrograms/meter^3
H	Plume rise, adapted from Briggs (1969, 1971, 1972) and as recommended by Turner (see Plume Rise discussion)	meters
L	Length of fired-line adaptation	meters
M	Mixing height, the height in the atmosphere to which turbulent mixing occurs	meters
N	Reflection numbers (as smoke bounces off the ground or stable layers) after Bierly and Hewson (1962)	nondimensional
q	Emission rate per unit length of fired-line adaptation (equivalent to ER)	micrograms/meter-second
u	Transport windspeed	meters/second
y	Variable crosswind distance from midpoint of fireline to the limits $\pm$ L/2σ_y	meters
σ_y	Horizontal standard deviation of plume concentration distribution	meters
σ_z	Vertical standard deviation of plume concentration distribution	meters
1.2 and 1.6	Adapted coefficients resulting from combination of terms with the 0.6 coefficient for the 60 - percent entrained and 40 - percent unentrained smoke covered under Plume Rise.	nondimensional

Besides being a complex series of terms, Equation (5) calls for certain inputs which are difficult to derive. Some simplifications can be achieved by solving for the relative concentration, $\frac{\chi u}{q}$ on the left-hand side. Transport windspeed, u, and mixing height, M, are readily obtainable for field application, but the remaining three variables on the right—horizontal and vertical standard deviation of plume concentration distribution, σ_y and σ_z, and plume rise, H, all call for more than the equation itself.

This need for further adaptation brought us to three alternatives:

1. Using a computer program to generate a series of graphs or look-up tables
2. Offering a computer program in a form that could be accessed by users
3. Providing a combination of look-up tables and typical cases with predicted concentrations that could be adjusted to actual cases.

The first of these alternatives resulted in such an unwieldy set of tables, graphs, instructions, and intermediate calculations that it was discarded. Alternative No. 2 is in progress at this writing. Recognizing the value of close exposure to the actual procedures, and recognizing as well that some users would not have immediate access to automatic data processing, we have pursued alternative No. 3 in this Guidebook.

PLOTTING RESULTS OF CALCULATIONS

When ground-level dispersion patterns calculated with a modified Gaussian distribution model are plotted to scale, they will typically show curves like those of figure 21.

Because of possible deviations of the actual wind direction from the forecast, and the need to avoid underestimating smoke impact at designated targets, the Gaussian model is not used in unmodified form for predicting downwind smoke

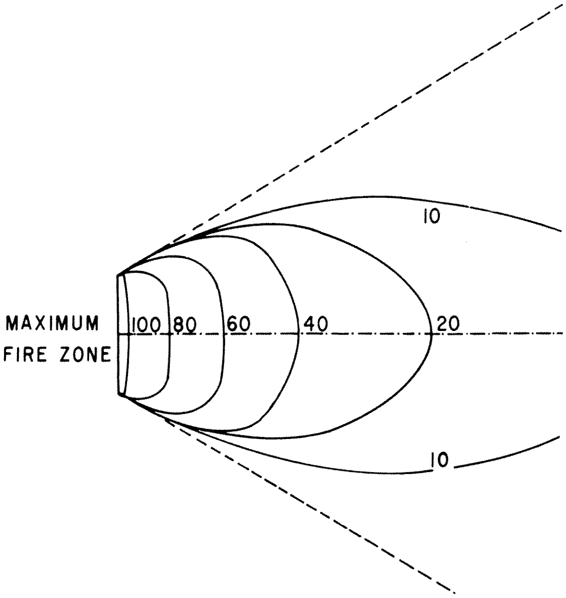


Figure 21. — Ground-level dispersion patterns from a modified Gaussian distribution model. Concentrations are shown on a hypothetical scale of 100 for ease of visualizing changes.

concentrations. Rather, a system that extends the centerline concentrations 30° to either side of the expected downwind direction is used. A possible promise of partially reducing this admittedly conservative allowance, as well as others, lies in automatic data processing for predicting trajectories and concentrations on the day of burning. This promise lies in an ability to work with more massive data from localized weather forecasts which are adjusted over time as the smoke plume travels downwind. While the technology is available now, a conservative procedure must be suggested for use until adaptive work in progress can be completed.

The presently suggested procedure calls for plotting the crosswind length of the line to be fired and plotting a downwind trajectory from the center point of that line. From the ends of the line, downwind trajectories are plotted as dashed lines for a distance of twice the crosswind length of the fired line. From these end trajectories, lines of the limits of possible smoke impact are drawn at 30° outward angles. The trapezoid-like figure that results depicts the area of probable smoke impact.

Concentrations in the impact area are determined by striking arcs through the centerline trajectory at specified distances. At distances less than twice the crosswind line length, two arcs should be struck using the line end points as centers. The two end point arcs are then connected by a straight line passing through the trajectory centerline. Beyond two fired-line lengths downwind, this procedure may be satisfactorily approximated by simply drawing a single arc between the smoke impact limits with the middle of the crosswind line as the center for the arc. The resulting plot, like the one shown in figure 22, differs from figure 21 by intention. This difference allows for a plot of predicted maximum concentrations by zones that extend through the centerline to either edge of the trajectory, thereby avoiding underestimates of concentration due to transient or unexpected wind or centerline shifts.

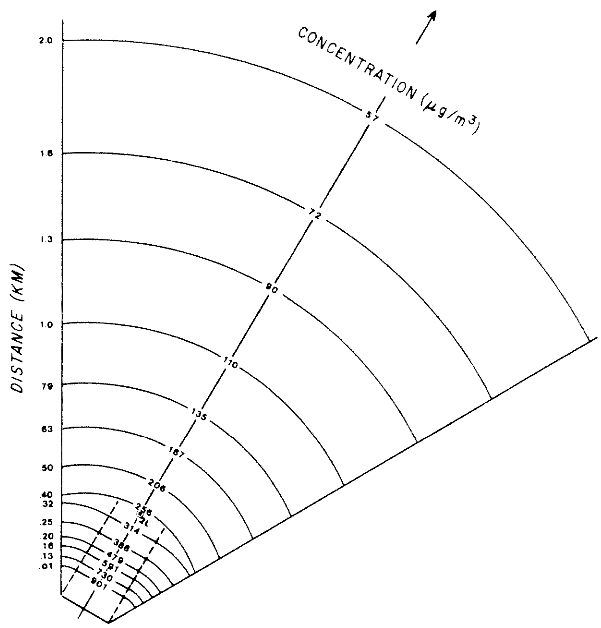


Figure 22. — Plot of predicted centerline concentrations like those to be employed in Chapter VI. The "2L" point indicates twice the fired-line length.

When completed, these plots are used to obtain a total predicted concentration at any potential downwind target by adding the concentration within the zone defined by an arc to the "background" pollutant concentration at the potential target. This permits rapid comparison of total predicted concentrations with acceptable concentrations for all potential targets.

A rule of thumb (Noll and others 1968) can be employed to estimate "background" pollutant concentrations when these have not been quantified by other means. The rule is limited to relative humidities of 70 percent or less and to particulate matter 0.3 micron in diameter and larger. To use the rule, 730 micrograms per cubic meter per mile are divided by the visibility in miles. For example, if the visibility is 5 miles, the "background" pollutant concentration is estimated to be:

$$\frac{730\,\mu g/m^3/mi}{5\,mi} = 146\,\mu g/m^3$$

LONG-RANGE TRANSPORT

Transport of emissions beyond the 100 km (62 miles) limit of the model employed becomes a new predictive problem. Because this problem is almost in a province of regional smoke management, we have made no attempt to provide any adaptation from among the best of several models under study at this time. We have, however, recognized the importance of the normally stable trend toward evening. At the same time, we have attempted to provide a margin of safety to help assure the manager that smoke from a single burn will not contribute to problems beyond 100 km. To do this, we devised a procedure called *Long-Range Transport Margin* which is incorporated in Chapter VI.

BASIS FOR LONG-RANGE TRANSPORT MARGIN

For fires in fuel types known to be relatively heavy emitters, when the convective-lift fire phase will extend beyond 3 hours before sunset, users will find themselves referred to figure VI-M-1 in Chapter VI. To use figure VI-M-1, a graphic intersection of the fire emission rate (ER) and transport windspeed is located. If the intersection is either to the left of, or upon, the sloping internal line

$$\frac{qL}{u} = 7.5 \times 10^8 \text{ micrograms/m}^2\text{-sec,} \qquad (6)$$

the burn may be considered *safe*. If the intersection is to the right of the line, the fire prescription should be modified.

The principal consideration underlying this procedure is to avoid carrying concentrations of particulate matter in excess of 150 micrograms per cubic meter beyond 100 km when stable conditions can be expected.

The following assumptions have been made in constructing figure VI-M-1:

1. D stability

2. No plume rise (because at 100 or more km a plume is well mixed within the mixing layer)

3. Point source (source configuration is of no consequence at 100 km)

4. Relative concentration, $\frac{\chi u}{qL}$, at 100 km is 2×10^{-7} meter^{-2}, which is consistent with 150 micrograms/m^3; variables are the same as previously listed.

LIMITATIONS OF THE MATHEMATICAL MODEL

Of the essential model, Turner (1970) points out that it "... may provide *best estimates* but not infallible predictions." We offer the adapted model in this same frame of reference. In addition to other limitations mentioned in preceding discussions, it is particularly important to note that as the smoke disperses with time, stability and other weather variables will change. The present model does not account for these changes. We have, however, covered one procedure adapted from the model to provide a margin of safety for long-range transport. This procedure is made part of those in Chapter VI to partially compensate for changes in stability. Finally, the user of the procedures in Chapter VI must recognize limitations in the accuracy of weather forecasts. In making these *best estimates* the user is allowing for upward and downward mixing within a zone of concentration. As a consequence, not all potential targets will be receptors at any given instant. He is portraying the potential concentration at each target.

LITERATURE CITED

Barad, M. L., and D. A. Haugen

1959. A preliminary evaluation of Sutton's hypothesis for diffusion from a continuous point source. J. Meteorol. 16(1):12-20.

Bierly, E. W., and E. W. Hewson

1962. Some restrictive meteorological conditions to be considered in the design of stacks. J. Appl. Meteorol. 1(3):383-390.

Briggs, G. A.

1969. Plume rise. Air Resour. Atmos. Turbul. and Diffus. Lab., Environ. Sci. Serv. Adm., U.S. Atomic Energy Comm., 81 p., Oak Ridge, Tenn.

Briggs, Gary A.

1971. Some recent analyses of plume rise observations. *In* Proc. Sec. Int. Clean Air Congr., p. 1029-1032, Acad. Press, New York.

Briggs, Gary A.

1972. Discussion, chimney plumes in neutral and stable surroundings. Atmos. Environ. 6(7):507-510.

Cramer, H. E., F. A. Record, and H. C. Vaughan

1958. The study of the diffusion of gases for aerosols in the lower atmosphere. Final Rep., Contract AF19(604)-1058, 70 p., Mass. Inst. of Tech., Dep. Meteorol., Cambridge, Mass.

Hay, J. S., and F. Pasquill

1957. Diffusion from a fixed source at a height of a few hundred feet in the atmosphere. J. Fluid Mech. 2, Part 2, p. 299-310.

Holzworth, George C.

1972. Mixing heights, windspeeds, and potential for urban air pollution throughout the contiguous United States. U. S. Environ. Prot. Agency, Off. Air Programs, Publ. No. AP-101, 118 p., Research Triangle Park, N.C.

Hosler, Charles R.

1961. Low-level inversion frequency in the contiguous United States. Mon. Wea. Rev. 89(9):319-339.

Korshover, Julius

1971. Climatology of stagnating anticyclones east of the Rocky Mountains, 1936-1970. NOAA Tech. Memo. ERL-ARL-34, 27 p., U. S. Dep. Commer., Natl. Oceanic & Atmos. Adm., Silver Spring, Md.

Lavdas, Leonidas G.

1976. A groundhog's approach to estimating insolation. J. Air Pollut. Control Assoc. 26(8):794.

Noll, Kenneth E., Peter K. Mueller, and Miles Imada

1968. Visibility and aerosol concentration in urban air. Atmos. Environ. 2(5):465-475.

Pasquill, F.

1972. Factors determining pollution from local sources in industrial and urban areas. The Meteorol. Mag. 101(1194):1-8.

Pasquill, F.

1975. Atmospheric diffusion. 2d ed., p. 368. John Wiley and Sons, New York.

Reiquam, H.

1970. An atmospheric transport and accumulation model for airsheds. Atmos. Environ. 4(3):233-247.

Schroeder, Mark J., and Charles C. Buck

1970. Fire weather ... A guide for application of meteorological information to forest fire control operations. USDA For. Serv. Agric. Handb. 360, 228 p., USDA For. Serv., Washington, D.C.

Turner, D. Bruce

1970. Workbook of atmospheric dispersion estimates. U. S. Environ. Prot. Agency, Off. Air Programs, Publ. No. AP-26, 84 p., Research Triangle Park, N.C.

Williams, Dansy T.

1974. A smoke volume model for prescribed fire. *In* Proc. Symp. on Atmos. Diffus. & Air Pollut.: Santa Barbara, Calif., p. 159-162. Publ. by Am. Meteorol. Soc., Boston, Mass.

CHAPTER VI
HOW TO MANAGE SMOKE

by

John M. Pierovich, Program Manager
Ragnar W. Johansen, Research Forester
Leonidas G. Lavdas, Research Meteorologist
Hugh E. Mobley, Technical Specialist
James A. Pharo, Research Meteorologist
Charles D. Tangren, Physical Scientist
Southern Forest Fire Laboratory
Southeastern Forest Experiment Station
USDA Forest Service
Macon, Georgia

This Chapter is written to help manage smoke from forestry prescription burning once the decision to burn has been made. No attempt is made here to evaluate alternatives to burning. Sometimes, the logic steps may lead to a suggestion that the decisionmaker take a new look at other possible treatments. We will first discuss the concepts of smoke management planning and then present a decision-logic procedure. Part 3 of this Chapter contains tables needed to follow some of the more complex logic.

PART 1. PLANNING FOR SMOKE MANAGEMENT

A written burning plan should be prepared in advance for each area to be burned. It should contain a scheduling system and prescription elements that aim at both accomplishment of objectives and avoidance of unwanted air quality effects. We suggest that, as used, the worksheets presented in Part 2 of this Chapter be attached to file copies of completed plans.

SCHEDULING

The number of days during a season with conditions fitting both resource management objectives and air quality objectives is limited. As a consequence, it is likely that the number of large burns will increase on the few days when both sets of constraints are met. Smoke from several forestry sources could tax the smoke-absorbing capacity of target-area atmospheres on these days. A need for systematic and careful scheduling of burns is called for.

A scheduling system that minimizes the effects on air quality should include the following elements:

An analysis of the number of days each year when weather is likely to meet both management objectives *and* air quality objectives

The numbers, sizes, and locations of desired burns listed by priority and difficulty of burn—along with likely-best smoke plume trajectories

A method of allocating available days to desired burns

A procedure for selecting alternate burn tracts when unfavorable weather conditions prevent following the schedule

An inventory of expected *background* particulate matter concentrations in areas likely to be downwind from prescribed burning operations.

PLANNING CHECKLIST

1. Follow a formally prepared plan.
2. Be sure all legal requirements are met.
3. Provide in advance for burning permit, receipt of weather forecasts, and prior measurement of variables like total litter layer moisture content.
4. When windrowing and piling debris, provide for best drying and avoid mixing with dirt.
5. Follow a decision logic to determine the kind of day on which you should be able to burn with good smoke management.

6. Use localized weather information, asking for spot fire-weather forecasts and updates.

7. Burn when wind will not carry smoke into sensitive areas (targets).

8. Seek unstable weather conditions, but not extremes.

9. Avoid days with low morning transport windspeed (less than 4 mph).

10. Avoid days with low morning mixing heights (less than 500 meters).

11. Seek dry fuel conditions, but not extremes.

12. Seek low relative humidity, but not extremes.

13. Be cautious of nighttime burning (if permitted).

14. Be especially cautious when burning a large area or a heavy loading of fuel.

15. Use firing technique that produces the least emissions.

16. Be prepared to mop up stumps and snags, especially if large and decaying.

17. Make last-minute check on weather conditions.

18. Remember that fires have to be controlled, and timber should not be excessively scorched; as dispersal conditions improve, fire intensity increases.

19. Be alert for a change in weather conditions.

PRESCRIPTION ELEMENTS

Combinations of the following fire prescription elements are necessary to plan for maintenance of air quality. Some variables that are foreign to foresters will be needed for smoke management. In the list of elements which follows, numbers in parentheses refer to the decision-logic stages where each is used:

Fuel type (No. 1 and No. 2)
Age of rough (No. 1 and No. 2)
Total litter layer moisture content (No. 2)
Fine fuel moisture (No. 2)
Firing pattern (No. 2)
Length of fired line (No. 1 through No. 3)
Relative humidity (No. 2)
Air temperature (No. 2)
Stability (No. 1 and No. 3)
Mixing height (No. 1)
Surface windspeed and direction (No. 1 and No. 2)
Transport windspeed and direction (No. 1, No.3, and No. 5).

PART 2. DECISION LOGIC

INTENDED USE AND LIMITATIONS

You are now well aware of the large amount of information that must be integrated to determine if fire prescriptions will meet air quality objectives. To accomplish this task, we have developed a decision-logic system for applying the best knowledge available. The system applies the mathematical models and concepts discussed in Chapters IV and V. The criteria for the system are discussed in Chapter III under A VOLUNTARY DECISION PROCEDURE PROPOSED FOR FORESTRY SMOKE MANAGEMENT, starting on page 26.

The system calls for the user to specify his own fire prescription elements and to adopt acceptable levels of total suspended particulate matter (TSP) for target areas downwind. While designed for advance planning, the system should also be used on the day of burning with actual and forecast values substituted for prescribed values.

Our intent is to provide the easiest possible procedure to *AVOID OVERLOADING NATURAL CLEARANCE MECHANISMS.* A model is a representation of beliefs about a natural system, not necessarily what actually takes place. For manageability, models used for dispersion calculations and for heat release rate (HRR) and emission rate (ER) calculations are dependent only upon values expected as averages for *steady-state* conditions during two discreet fire phases. We have chosen this course rather than attempt to impose more realistic, but exceedingly complex, equations—allowing for changes in state during the life of the burn. For these reasons, the logic system's predictions may be incorrect at times even though the system applies the best available technology.

OVERVIEW

The system is divided into six stages to keep the user oriented as he progresses. It is designed for desk-top calculations. As presented here, system responses to variability have been compressed to facilitate use. For example, in one instance, many separate operations and at least 32 tables are represented by only a few typical cases.

Stage No. 1 is for relatively simple screening of prescriptions. From it the user can decide to burn, not to burn, or to proceed with more detailed analyses in subsequent Stages. We expect that this first Stage will cover many prescription burns. Stages No. 2 through No. 5 apply to more complex situations where decisions are not immediately obvious. Stage No. 6 introduces automatic data processing options. 5/

Stage No. 2 is the logic for determining fuel and fire characteristics so that emission rate and heat release rate can be calculated. Stage No. 3 provides for determining a margin of safety for concentrations carried long distances. In Stage No. 4, the user matches his prescription variables to typical burning cases. Provision is made to correct for differences between presented and typical cases. Then, downwind concentrations of total suspended particulate matter can be calculated. In Stage No. 5, comparisons are made between predicted and user-specified total suspended particulate matter concentrations at targets. Decisions to be reached at this point are: to follow the burn prescription, to revise the prescription further, to find an alternative to burning, or to proceed with an analysis that requires automatic data processing.

5/ Programs will be provided in the Forestry Smoke Management Sourcebook.

We recognize that small landowners will find Stages No. 2 through No. 5 especially bothersome without technical staff or assistance. An adaptation of Stage No. 1 has been published for their use in uncomplicated situations (Tangren 1976).

In more complex situations, there are no easy ways to determine smoke dispersion without automatic data processing.

For those who do not have access to a computer, the desk-top decision-logic procedure will seem tedious. We believe it is the only way, however, to assure proper analyses, and we advocate its initial use even for those who have access to automatic data processing.

USE OF WORKSHEETS

Each Stage of the logic is presented in worksheet format. It is suggested that you make copies of these worksheets (yellow pages). Save one set of copies for future use as an original, then use extra copies as working papers to include with each burn plan and prescription.

DECISION-LOGIC STAGE #1: INITIAL SCREENING

To use this decision logic you should have already prepared a written prescription, and you should be familiar with applicable air quality rules, regulations, and standards. If there are no obvious situations that preclude burning, you are ready to proceed.

This Stage will help you decide if your prescription calls for a burn that is:

possible without modification
possible with modification
not possible.

We believe most prescribed fires will fall into the first two categories.

Steps 1.2 and 1.3 contain questions to be answered YES or NO. If all applicable questions are answered YES, the burning prescription can be followed without modification. Burning is still possible if all NO answers can be changed to YES by modifying the fire prescription; for example, by calling for another time to burn when mixing heights are more favorable, or when the transport wind direction will not carry smoke into target areas. If you answer NO and cannot modify the prescription to be able to answer YES, you should not burn unless you favorably complete a more detailed analysis in Stages #2 through #5.

1.1 PREPARATION

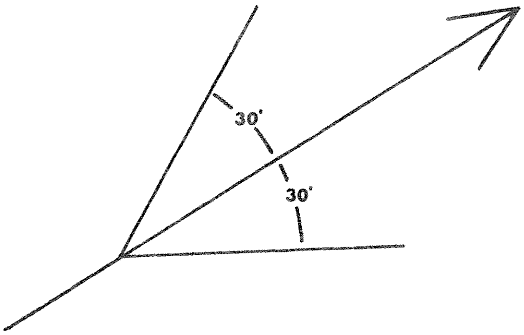
1.1a Wind Direction and Targets:

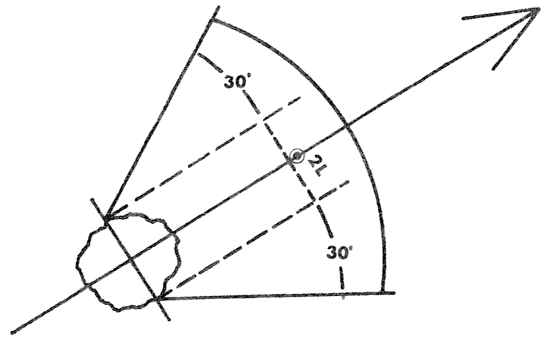
(1) Obtain map(s) covering improvements detail for 60 miles downwind from burn. Obtain azimuths of paths from burn prescription for both the convective-lift (CL) and the no-convective-lift (NCL) fire phases. Locate burn on map and, using protractor and straight edge, draw lines representing centerline of paths of smoke plume. Use two different colors to plot the two phases. Then check here and proceed. ______

Prescription specifics:

Convective-lift phase transport wind azimuth ________°
No-convective-lift phase transport wind azimuth ________°
(NCL is omitted for backing fires)

(2) Now you must allow for the width of the fire and shifts of the smoke plume centerline. Plot as in figure A if the fire is represented by a small dot. If it is larger, plot as in figure B.





Within the plotted areas, look for any improvements or other potential target (e.g.: town, Air Quality Maintenance Area, highway, village, hospital, factory, residence, airfield, etc.) that you consider critical from an air quality standpoint. Then check here and proceed.

_____

(3) If in rare cases no potential targets are found, this logic need not be applied, and you may burn without further use of the procedure. If any targets are identified, you should continue with the procedure. Attach your map(s) to this Worksheet and check *one* of the following:

Target(s) identified, logic will be applied
(go on to Step 1.b)_____
No target(s) identified, logic need not be
applied further (Stop)_____

1.1b Fuel Type:

(1) At this time, research is not sufficiently complete to cover other than the following fuel types. If your fuel type is other than the ones listed, you must decide if one of these is reasonably comparable to proceed through the rest of the logic *using this type*, or you must plan your prescription without aid of the logic system.

Palmetto-gallberry_____
Grass with pine overstory_____
Pine needle litter_____
Light brush_____
Unpiled pine logging debris_____

(2) Check the appropriate fuel type above if yours matches, or if you select a type as nearly comparable as you can.

(3) If you selected a comparable type, circle the checkmark.

(4) If you checked none of the types listed, you may wish to use this Stage #1 Worksheet, but do so with special caution and *do not attempt to use Stages #2 through #6*.

(5) Now check one of the following:

Type matches or comparable type selected, and logic will be applied _____
Type does not match, and comparable type not selected
but Stage #1 will be applied_____
and Stage #1 will not be applied_____

1.2 CRITICAL TRAJECTORIES

If a NO answer is given to any of the following questions, it is most desirable to prescribe a new *transport wind direction* to avoid target areas in question. *Be sure to also rework Step 1.1a to reflect the new prescribed azimuths.*

If you cannot prescribe a new wind direction you should proceed immediately with Stages #2 through #5, but be prepared to encounter downwind concentrations that may not be acceptable.

1.2a Sulfur Dioxide Interactions:

Does your trajectory avoid the chance that critical sources of atmospheric emissions containing SO_2 will merge with the emissions from your burn.[1]

YES _____
NO _____

1.2b Unacceptable Background Level:

Are all identified target areas likely to be free from other known air pollution problems at the time of burn? (Allow for other forestry burning.)

YES _____
NO _____

1.2c Is the area within 3/4 mile of your burn free of targets?

YES _____
NO _____

1.3 MINIMIZING RISK

You should always determine if you can readily change your prescription to obtain a YES answer whenever you have checked NO in this set of questions.

---

[1]Sulfur dioxide, SO_2, is believed by many authorities to become a more likely health hazard in the presence of particulate matter from any source. If local guidance on critical sources is not available to you, a good rule is to avoid all sources.

1.3a Is your fuel type other than logging debris?

YES ______[2]
NO ______

1.3b For all other fuel types if your rough is older than 2 years, is a backing fire prescribed and is total fuel loading less than 10 tons per acre?[3]

YES ______[2]
NO ______

1.3c Will the burn be conducted when background visibility is likely to be at least 5 miles at all points within the first 60 miles along the plotted trajectory? (Step 1.1a)

YES ______
NO ______

1.3d Are all other known or expected sources of emissions (including other prescribed burns) displaced to the side of your plotted trajectory (Step 1.1a) by a distance of at least one-half their downwind distance and are any targets in overlapping area farther than 2 km (1.2 miles)?

YES ______
NO ______

1.3e Does your prescription call for the forecast mixing height to be 500 meters or more?

YES ______
NO ______

1.3f Is the prescribed transport windspeed 4 or more meters per second?

YES ______
NO ______

1.3g If your plan calls for a night burn, have you prescribed a surface windspeed greater than 4 mph and a backing fire?

YES ______
NO ______
NOT APPLICABLE ______

---

[2] Go directly to Stage #2 since prescription cannot be changed.

[3] This question reflects the application of current best available technology in limiting total suspended particulate matter (TSP) regardless of chemical nature.

1.3h If a burning permit is locally required, do your prescription elements match *permit* requirements and does your plan call for obtaining the required permit?

YES _____
NO _____ [4]
NOT APPLICABLE _____

NOTE: You now have a set of answers to help you screen your prescription. If you have completed the preparatory Steps in Steps 1.1 and have now answered YES to all questions asked in Steps 1.2 and 1.3, you do not need to go on to Stages #2 through #5. Instead, it is likely your prescription will provide for good smoke management and you are ready to burn. If you have answered NO and cannot revise your prescription, you should not burn until you have favorably completed Stages #2 through #5.[5]

---

[4] Do not proceed to Stage #2 if permit is required and NO has been answered.

[5] CAUTION: Stages #2 through #6 are likely to yield DO NOT BURN decision advice if you are using any of the following:

Less than 500 meters mixing height
Less than 4 mph surface windspeed
Less than 4 meters per second transport windspeed
Background visibility on trajectory less than 5 miles.

SPECIAL INTRODUCTION TO STAGES #2 THROUGH #5

If an automatic data processing procedure for smoke management decisions is available to you, you should skip immediately to Stage #6.

The following interrelated parameters are needed to predict total downwind concentrations that will be used for comparisons with acceptable concentrations. The variables used to derive them are provided.

Parameter	Variables
Total litter layer moisture content	Previous litter layer moisture content, age of rough, yesterday's duration of precipitation (see Chapter IV).
Fuel loading	Fuel type, age of rough, stand basal area, understory height (palmetto only), average d.b.h. (logging residue only), cords cut (logging residue only).
Available fuel	Fuel type, fuel loading, total litter layer moisture content.
Emission factor	Fuel type, combustion stage, age of rough, burning method.
Fire phase	Heat release rate.
Combustion stage	Fire behavior.
Fine fuel moisture	Temperature, relative humidity, sky condition (grass only).
Stand characteristics	Preburn inventory or preharvest inventory.
Rate of spread	Fine fuel moisture, windspeed at midflame height, fuel type.
Length of fired line	Prescription, plot geometry (for ring fires only).
Heat release rate	Available fuel, rate of spread, length of fired line.
Particulate matter emission rate	Available fuel, rate of spread, emission factor.
Mixing height	Observed and forecast weather.
Transport windspeed and direction	Observed and forecast weather.
Stability class	If not forecast by the National Weather Service: solar angle (shadow length), cloud cover and height, 10-meter windspeed (see Chapter V).
Target-area *background* concentrations	Effects of other emissions sources.

This decision logic does not apply to slopes greater than 20 percent.

Two sets of reference figures and tables will be used in working through the logic stages. The first set (tables VI-F-1 through VI-F-13) is related to fuels and fire behavior and is printed on pink paper. The second set (tables VI-M-1 through VI-M-6 and figure VI-M-1) is related to meteorology and is printed on blue paper. Many calculations are represented by these figures and tables. Derivations are explained in Guidebook Chapters IV and V.

In preparing to use the Stages, it is important to recognize two constraints in the system presented:

1. For each fuel type, an average emission factor (EF) has been derived for the most likely fuel conditions. We know that moisture and other variables will affect the EF, but believe the current state of knowledge does not warrant further refinement in calculations at this time.

2. The strategy here is to limit concentrations of total suspended particulate matter (TSP). Future control strategies may include control of specific components of smoke.

DECISION-LOGIC STAGE #2: RATE DETERMINATIONS

You have been directed here from Stage #1 because one of your responses indicated a degree of risk calling for more complex analyses, and/or you were unable to modify your fire prescription.

From the list of parameters in the Special Introduction preceding this Stage, you will have noted a number of new prescription elements. Your prescription will require more detail, and we suggest you prepare the prescription as you work through this and subsequent Stages--adding new variables as needed.

CAUTION: Do not proceed unless your prescription calls for a relative humidity of less than 71 percent during the convective-lift and no-convective-lift phases. (Predictions above this humidity are not to be used and the logic does not apply.)

A. DETERMINATION OF STAGE #2 WORKSHEET SET TO BE USED:

The fuel type you selected in Step 1.1b was (check one, then proceed to next step on indicated Worksheet Set):

Palmetto-gallberry _____	Go directly to Worksheet Set 2B
Grass with pine overstory _____	Go directly to Worksheet Set 2C
Pine needle litter or light brush _____	Go directly to Worksheet Set 2D
Unpiled pine logging debris _____	Go directly to Worksheet Set 2E.

DECISION-LOGIC STAGE #2 APPLIED TO PALMETTO-GALLBERRY FUEL TYPE
You Have Been Directed Here From Worksheet Set 2A

2B.1 FUELS

2B.1a Make the following entries from your inventory of the burn area:

(1) Stand basal area is _____ sq ft/acre
(2) Age of rough is _____ yr
(3) Predominant overstory timber species is (check one):
  Slash pine _____
  Loblolly pine _____
(4) Average height of understory component is _____ ft

2B.1b With entries (1), (2), and (3) from above, use table VI-F-5 if the predominant species is slash pine, or use table VI-F-6 if the predominant species is loblolly pine, to determine the total litter weight, entering the value here:

_____ ton/acre

2B.1c With entries (2) and (4) from above, use table VI-F-9 to determine the understory vegetative dry weight, entering the value here:

_____ ton/acre

2B.2 TOTAL LITTER LAYER MOISTURE CONTENT

2B.2a Prescribe a maximum total litter layer moisture content (TLLMC). (Review Southern Forestry Smoke Management Guidebook Chapter IV for procedure and requirements.) The TLLMC will be:

_____ %

2B.2b Assure that the burning plan provides for observing and recording actual TLLMC. Then return here, check, and proceed to next step.

_____

2B.3 TOTAL AVAILABLE FUEL

2B.3a With the total litter weight you determined in Step 2B.1b, the understory vegetative dry weight you determined in Step 2B.1c, and the prescribed maximum TLLMC you entered in Step 2B.2a, use table VI-F-10 to determine the estimated total available fuel (litter and vegetation), entering the value here:

_____ ton/acre

2B.4 PINE NEEDLE MOISTURE CONTENT AND BURNING METHOD

2B.4a Make the following entries from your written prescription for subsequent use:

Maximum relative humidity _____%
Minimum windspeed (20-foot tower) _____ mph
Burning method (check one):
Heading fire _____
Backing fire _____

2B.4b With the relative humidity entry from above, use table VI-F-3 to determine the pine needle litter moisture content, entering the value here: _____ %

2B.5 WIND EFFECT

2B.5a If you have prescribed a heading fire, divide windspeed you entered in Step 2B.4a by 4 to arrive at an estimated midflame windspeed, entering the value here; if you have prescribed a backing fire, enter a zero here: _____ mph

2B.6 RATE OF SPREAD

2B.6a With the pine needle litter moisture you determined in Step 2B.4b and the windspeed you determined in Step 2B.5a (the windspeed used here for a backing fire is always 0), use table VI-F-11 to determine rate of spread, entering the value here:

_____ ft/min

2B.7 COMBUSTION STAGES

2B.7a Because a sizable fraction of the fuels, when heading fired, will remain to be consumed in the residual combustion stage after the advancing-front combustion stage passes, an adjustment is needed to proportion the amount of fuel available to each stage. A suggested advancing front:residual ratio of fuel consumed is 50:50. When backing fires are employed, almost all of the fuel is consumed during the advancing-front combustion stage, and a ratio of 1:0 is appropriate. Now select the values you judge most appropriate and enter here:

(1) Decimal fraction of fuel consumed in advancing-front stage (y_A) _____
(2) Decimal fraction of fuel consumed in residual stage (y_R); ($1.00 - y_A$) _____

2B.8 EMISSION FACTORS

2B.8a The suggested TSP emission factors (EF) for the palmetto-gallberry type are:

Age of rough and burning method	Emission factors (lbs/ton) Advancing-front stage EF_A	Residual stage EF_R
≤2 years backing or heading and >2 years backing	25	None
>2 years heading	25	125

Now, opposite your age of rough and burning method, either circle the EF value(s) to be used or enter new values if better data are available to you.

2B.9 EMISSION RATES

2B.9a Perform the indicated multiplications by entering the values from the steps shown in the following equations.

(1) Calculate ER_A, the total suspended particulate matter (TSP) emission rate, for the advancing front combustion stage:

ER_A = 570 x ________________ (Available fuel from Step 2B.3a) x ________________ (Rate of spread from Step 2B.6a)

x ________________ (Consumption adjustment (y_A) from Step 2B.7(1)) x ________________ (EF_A from Step 2B.8a)

ER_A = __________ micrograms TSP/meter-second (μg TSP/m-sec)

(2) If your prescription is for a backing fire in any age rough, or for a heading fire in rough 2 years old or less, skip directly to Step 2B.9b.

If your prescription is for a heading fire in rough more than 2 years old, calculate ER_R, the TSP emission rate for the residual combustion stage:

ER_R = 570 x ________ x ________
(Available fuel from Step 2B.3a) (Rate of spread from Step 2B.6a)

x ________ x ________
(Consumption adjustment (y_R) from Step 2B.7a(2)) (EF_R from Step 2B.8a)

ER_R = ________ μg TSP/m-sec

(3) Now calculate ER_{A+R}, the TSP emission rate for the convective-lift phase of heading fires in rough older than 2 years:

ER_{A+R} = ________ + ________
(ER_A from Step 2B.9a(1)) (ER_R from Step 2B.9a(2))

ER_{A+R} = ________ μg TSP/m-sec

2B.9b If you were told to skip to this Step from Step 2B.9a(2), enter the value of ER_A, from Step 2B.9a(1) in the blank below for ER_{CL}, and NONE in ER_{NCL} below, then skip directly to Step 2B.10.

If you calculated ER_{A+R} in Step 2B.9a(3), enter the value for ER_{A+R} in the blank below for ER_{CL}, then enter the value for ER_R from Step 2B.9a(2) in the blank below for ER_{NCL}.

ER_{CL} = ________ μg TSP/m-sec

ER_{NCL} = ________ μg TSP/m-sec

2B.10 HEAT RELEASE RATE

2B.10a Make the following entry from your written prescription:

Length of fired line _____ft

2B.10b Using the length of fired line from the Step immediately above and the same weight of available fuel and rate-of-spread values just used in Step 2B.9a, calculate the heat release rate (HRR) for the convective-lift phase of your fire. Heat release has negligible effect for the no-convective-lift phase.

HRR_{CL} = 0.0012 x ________ x ________
(Available fuel from Step 2B.3a) (Rate of spread from Step 2B.6a)

x ________ x ________
(Consumption adjustment (y_A) from Step 2B.7a(1)) (Length of fired line Step 2B.10a)

HRR_{CL} = ________ megacal/sec

NOW SKIP DIRECTLY TO STAGE #3

DECISION-LOGIC STAGE #2 APPLIED TO GRASS WITH PINE OVERSTORY FUEL TYPE

You Have Been Directed Here From Worksheet 2A

2C.1 FUELS

2C.1a Make the following entries from your inventory of the burn area for subsequent use:

(1) Age of rough _____ yr
(2) Stand basal area _____ sq ft/acre
(3) Predominant overstory (check one):

Slash pine _____
Loblolly pine _____

2C.1b With entry (1) from above, use table VI-F-1 to determine the total available grass weight, entering the value here:

_____ ton/acre

2C.1c With entries (1), (2), and (3) from above, use table VI-F-5 if the predominant overstory is slash pine, or table VI-F-6 if the predominant overstory is loblolly pine, to determine the total needle litter weight, entering the value here:

_____ ton/acre

2C.1d Compare the entry you made for the grass weight in Step 2C.1b with the entry you made for the needle litter weight in Step 2C.1c. Is the grass component greater?

Yes _____ then proceed to Step 2C.2
No _____ then skip directly to Worksheet 2D and reclassify fuel type as pine needle litter, the more applicable fuel type.

2C.2 WINDSPEED AND RELATED PRESCRIPTION ELEMENTS

2C.2a Make the following entries from your written prescription for subsequent use:

Expected cloud cover (check one): Sunny _____
Cloudy _____
Minimum windspeed (20-foot tower) _____ mph
Temperature _____ °
Maximum relative humidity _____ %
Burning method (check one): Heading fire _____
Backing fire _____

2C.2b If your prescription calls for a backing fire, skip directly to Step 2C.3.

If your prescription calls for a heading fire, divide windspeed you entered above by 4 to arrive at an estimated midflame windspeed, entering the value here:

_____ mph

2C.3 RATE OF SPREAD

2C.3a Use the appropriate prescription entries in Step 2C.2a with table VI-F-2 to determine fine fuel moisture for dead grass, entering the tabular value here:

_____ %

2C.3b If you completed Step 2C.2b, use the midflame windspeed, or for backing fires use a zero windspeed, along with this fine fuel moisture to determine the rate of fire spread for grass from table VI-F-4, entering the tabular value here:

_____ ft/min

2C.4 TOTAL LITTER LAYER MOISTURE CONTENT

2C.4a Prescribe a maximum total litter layer moisture content (TLLMC) (review Southern Forestry Smoke Management Guidebook Chapter IV for procedure and requirements). The maximum TLLMC will be:

_____ %

2C.4b Assure that the burn plan provides for observing and recording actual TLLMC. Then return here, check, and proceed to next step:

_____

2C.5 AVAILABLE LITTER FUEL

2C.5a With the total litter weight (needle fuel) you determined in Step 2C.1c and the prescribed TLLMC you entered in Step 2C.4a, use table VI-F-7 to determine the available fuel in pine needle and associated vegetative litter other than grass, entering this value here:

_____ ton/acre

2C.6 COMBINED TOTAL AVAILABLE FUEL

2C.6a Add the total available grass weight from Step 2C.1b to the available litter fuel from Step 2C.5a, entering the total here:

_____ ton/acre

2C.7 EMISSION FACTORS AND RATES FOR GRASS

2C.7a An emission factor (EF) of 15 pounds per ton of fuel consumed is suggested for grass fuels from experiments to date. Using this or other information available to you, select an EF appropriate to your prescribed burn, entering the value here:

EF = _____ lb/ton of fuel

2C.7b Using the determined values from the Steps shown in the following equation, calculate an emission rate (ER) by performing the indicated multiplications:

ER_A = 570 x _____________ x _____________
(Combined total available fuel from Step 2C.6a) (Rate of spread from Step 2C.3b)

x _____________
(EF from Step 2C.7a)

ER_A = _____ μg TSP/m-sec

2C.7c Since there is no appreciable residual combustion stage (and thus no no-convective-lift fire phase) for this fuel type with all burning methods, the advancing-front emission rate (ER_A) is equivalent to the convective-lift (CL) fire phase. For this reason, enter the ER_A value you determined in Step 2C.7b in the blank below:

ER_{CL} = _____ μg TSP/m-sec

2C.8 HEAT RELEASE RATE

2C.8a From your written prescription, enter here the length of fired line:

_____ ft

2C.8b Calculate the heat release rate (HRR) for your fire by entering the determined values from the Steps shown in the following equation and performing the indicated multiplications:

HRR_{CL} = 0.0012 x ______________________ x ____________________
(Combined total available fuel from Step 2C.6a) (Rate of spread from Step 2C.3b)

x ____________________
(Length of fired line from Step 2C.8a)

HRR_{CL} = _____ megacal/sec

DECISION-LOGIC STAGE #2 APPLIED TO PINE NEEDLE LITTER AND/OR LIGHT BRUSH
You Have Been Directed Here From Worksheet Set 2A, or by fuel type reclassification from Worksheet Set 2C

2D.1 FUELS

2D.1a (1) If you have been directed here from Worksheet Set 2A, skip directly to Step 2D.1b.

(2) If you have been directed here from Worksheet Set 2C, bring forward your entries from that Worksheet as follows:

Total available grass weight ________________ ton/acre
(from Step 2C.1b)

Pine needle total litter weight ________________ ton/acre
(from Step 2C.1c)

(3) Now skip directly to Step 2D.2.

2D.1b Make the following entries from your inventory of the burn area for subsequent use:

(1) Stand basal area is _____ sq ft/acre
(2) Age of rough is _____ yr
(3) Predominant overstory is (check one): Slash pine _____
Loblolly pine _____

2D.1c With the entries (1), (2), and (3) from above, use table VI-F-5 if the predominant species is slash pine, or use table VI-F-6 if the predominant species is loblolly pine, to determine the total litter weight, entering the value here:

_____ ton/acre

2D.2 TOTAL LITTER LAYER MOISTURE CONTENT

2D.2a Prescribe a maximum total litter layer moisture content (TLLMC) (review Southern Forestry Smoke Management Guidebook Chapter IV for procedure and requirements). The TLLMC will be:

_____ %

2D.2b Assure that the burn plan provides for observing and recording actual TLLMC. Then return here, check, and proceed to next step:

_____

2D.2c You will now use either the pine needle total litter weight from Step 2D.1a(2), if you completed this Step, or use the total litter weight from Step 2D.1c, if you completed this Step. With the value for total litter weight and the prescribed maximum TLLMC you entered in Step 2D.2a, use table VI-F-7 to determine the available litter fuel, entering the value here:

_____ ton/acre

2D.3 RATE OF SPREAD

2D.3a Make the following entries from your written prescription:

Relative humidity _____ %
Windspeed (20-foot tower) _____ mph
Burning method (check one): Heading fire _____
Backing fire _____

2D.3b With the relative humidity entry from above, use table VI-F-3 to determine the pine needle litter moisture content, entering the value here:

_____ %

2D.3c If you have a prescribed heading fire, divide windspeed you entered in Step 2D.3a by 4 to arrive at an estimated midflame windspeed, entering the value here; or if you have prescribed a backing fire, enter a zero:

_____ mph

2D.3d With the pine needle litter moisture content you determined in Step 2D.3b and the windspeed you determined in Step 2D.3c (the windspeed used here for a backing fire is always 0), use table VI-F-8 to determine rate of spread, entering the value here:

_____ ft/min

2D.4 COMBUSTION STAGES

2D.4a Because a sizable fraction of the fuels, when heading fired, will remain to be consumed in the residual combustion stage after the advancing-front combustion stage passes, an adjustment is needed to proportion the amount of fuel available to each stage. Limited laboratory data suggest the advancing-front:residual ratio of fuel consumed is 50:50. When backing fires are employed, almost all of the fuel is consumed during the advancing-front combustion stage and a ratio of 1:0 is appropriate. Now, select the values you judge most appropriate and enter here:

(1) Decimal fraction of fuel consumed in advancing-front stage (y_A): _____

(2) Decimal fraction of fuel consumed in residual stage (y_R) ($1.00 - Y_A$): _____

2D.5 EMISSION FACTORS

2D.5a The suggested total suspended particulate matter (TSP) emission factors (EF) for the pine needle/light brush fuel type are:

Age of rough and burning method	Emission factors (lbs/ton) Advancing-front stage EF_A	Emission factors (lbs/ton) Residual stage EF_R
$\leq$2 years backing or heading and >2 years backing	50	None
>2 years heading	50	180

2D.6 EMISSION RATES

2D.6a If you completed Step 2D.1a, add the total available grass weight in Step 2D.1a(2) to the available litter fuel you determined in Step 2D.2c, entering the sum in the blank space below.

If you completed Step 2D.1b, enter only the available litter fuel you determined in Step 2D.2c in the blank space below.

Total fuel available: _____ ton/acre

2D.6b Perform the indicated multiplications by entering the values from the Steps shown in the following equations.

(1) Calculate ER_A, the total suspended particulate matter (TSP) emission rate (ER) for the advancing-front combustion stage:

ER_A = 570 x __________ x __________
(Total fuel available from Step 2D.6a) (Rate of spread from Step 2D.3d)

x __________ x __________
(Consumption adjustment (y_A) from Step 2D.4a(1)) (EF_A from Step 2D.5a)

ER_A = _____ μg TSP/m-sec

(2) If your prescription is for a backing fire in any age rough, or for a heading fire in rough 2 years old or less, skip directly to Step 2D.6c.

If your prescription is for a heading fire in rough more than 2 years old, calculate ER_R, the TSP emission rate (ER) for the residual combustion stage:

$$ER_R = 570 \times \underset{\text{(Total fuel available from Step 2D.6a)}}{\underline{\qquad\qquad}} \times \underset{\text{(Rate of spread from Step 2D.3d)}}{\underline{\qquad\qquad}}$$

$$\times \underset{\text{(Consumption adjustment } (y_R) \text{ from Step 2D.4a(2))}}{\underline{\qquad\qquad}} \times \underset{\text{(}EF_R\text{ from Step 2D.5a)}}{\underline{\qquad\qquad}}$$

ER_R = _____ μg TSP/m-sec.

(3) Now, calculate ER_{A+R}, the TSP emission rate (ER) for the convective-lift phase of heading fires in rough older than 2 years:

$$ER_{A+R} = \underset{\text{(}ER_A\text{ from Step 2D.6b(1))}}{\underline{\qquad\qquad}} + \underset{\text{(}ER_R\text{ from Step 2D.6b(2))}}{\underline{\qquad\qquad}}$$

ER_{A+R} = _____ μg TSP/m-sec.

2D.6c If you were told to skip to this Step from Step 2D.6b(2), enter the value of ER_A from Step 2D.6b(1) in the blank below for ER_{CL}, and NONE in ER_{NCL}, below, then skip directly to Step 2D.7.

If you calculated ER_{A+R} in Step 2D.6b(3), enter the value for ER_{A+R} in the blank below for ER_{CL}, then enter the value for ER_R from Step 2D.6b(2) in the blank below for ER_{NCL}:

ER_{CL} = _____ μg TSP/m-sec

ER_{NCL} = _____ μg TSP/m-sec.

2D.7 HEAT RELEASE RATE

2D.7a Make the following entry from your written prescription:

Length of fired line _____ ft

2D.7b Using the length of fired line from the Step immediately above and the same weight of available fuel and rate-of-spread values just used in Step 2D.6b, calculate the heat release rate (HRR) for the convective-lift phase of your fire. (Heat release has negligible effect for the no-convective-lift phase.)

HRR_{CL} = 0.0012 x ______________ x ______________
(Available fuel from Step 2D.6a) (Rate of spread from Step 2D.3d)

x ______________ x ______________
(Consumption adjustment (y_A) from Step 2D.4a(1)) (Length of fired line from Step 2D.7a)

HRR_{CL} = _____ megacal/sec

NOW SKIP DIRECTLY TO STAGE #3

DECISION-LOGIC STAGE #2 APPLIED TO UNPILED LOGGING DEBRIS
You Have Been Directed Here From Worksheet Set 2A

2E.1 FUELS

2E.1a Enter here for subsequent use the following information from your inventory of the burn area:

(1) Average d.b.h. in cut timber stand _____ inches
(2) Species of timber cut (check one): Loblolly pine _____
Slash pine _____
(3) Total number cords removed from area _____
(4) Total acres in burn _____

2E.1b Using the diameter and species entries you made in Step 2E.1a (1) and (2), turn to table VI-F-12 to obtain the tons of logging residue fuel 1 inch in diameter and less per cord for your burn area, entering here:

_____ ton/cord cut

2E.1c Now, using entries you made in Step 2E.1a (3) and (4), divide the total number of cords removed entry by the total acres entry, then enter the result here:

_____ cord cut/acre

2E.1d Now, multiply the ton/cord cut entry you determined in Step 2E.1b by the number of cord cut/acre you determined in Step 2E.1c to calculate the available fuel per acre, entering the product here:

_____ ton/acre

2E.2 FUEL CONSUMPTION

2E.2a Lacking a more precise means to directly express a rate of fuel consumption for this fuel type, rate of fire spread for the fine fuels that dominate its initial spread will be used as a yardstick, and then adjusted. For this purpose, enter here the following elements affecting spread in fine fuels from your written prescription:

(1) Maximum relative humidity _____ %
(2) Surface windspeed (20-foot tower) _____ mph

2E.2b Using the relative humidity entry from Step 2E.2a (1), turn to table VI-F-3 to determine the pine needle moisture content, entering this value here:

Pine needle moisture content _____ %

2E.2c Convert your surface windspeed entered in Step 2E.2a (2) to midflame windspeed by dividing by 2.[5] Then turn to table VI-F-13 and use this converted windspeed value with the pine needle litter moisture value you determined in Step 2E.2b to determine rate of spread, entering the value here:

_____ ft/min

2E.3 COMBUSTION STAGES

2E.3a Because fire spread in fine fuels is only a yardstick by which to gauge emissions and heat yield, and because a sizable amount of the fuels will remain to smolder during the residual combustion stage, an adjustment is needed to proportion the amount of fuel available to each stage. Limited data suggest an advancing-front: residual ratio of 75:25 for fuel consumed. With this and other data available to you, select the values you judge most appropriate and enter here:

(1) Decimal fraction of fuel consumed in advancing-front stage (y_A) _____

(2) Decimal fraction of fuel consumed in residual stage (y_R); (1.00 - advancing-front stage) _____

2E.4 EMISSION FACTORS

2E.4a A total suspended particulate matter (TSP) emission factor (EF_A) of 35 pounds per ton of fuel consumed is suggested for the advancing-front stage. The suggested EF_R for the residual stage is 180 pounds TSP per ton of fuel consumed. As covered in Chapter IV, these values are appreciably higher than laboratory-determined values, but are suggested at this time as a conservative representation of the best overall information available.

From this information, select emission factors (EF) for your prescribed burn and enter here:

(1) EF_A = _____ lb TSP/ton

(2) EF_R = _____ lb TSP/ton

---

[5]A factor of 2 is used rather than 4, as in understory burns, because harvesting has removed sheltering trees.

2E.5 EMISSION RATES

2E.5a Using the determined values from the Steps shown in the equations that follow, calculate emission rates (ER) by performing the indicated multiplications:

(1) For the advancing-front stage:

$$ER_A = 570 \times \underset{\text{(Available fuel from Step 2E.1d)}}{\underline{\qquad\qquad}} \times \underset{\text{(Rate of spread from Step 2E.2c)}}{\underline{\qquad\qquad}}$$

$$\times \underset{\text{(Consumption adjustment } (y_A) \text{ from Step 2E.3(1))}}{\underline{\qquad\qquad}} \times \underset{\text{(}EF_A\text{ from Step 2E.4a(1))}}{\underline{\qquad\qquad}}$$

ER_A = _____ µg TSP/m-sec

(2) For the residual stage:

$$ER_R = 570 \times \underset{\text{(Available fuel from Step 2E.1d)}}{\underline{\qquad\qquad}} \times \underset{\text{(Rate of spread from Step 2E.2c)}}{\underline{\qquad\qquad}}$$

$$\times \underset{\text{(Consumption adjustment } (y_R) \text{ from Step 2E.3a(2))}}{\underline{\qquad\qquad}} \times \underset{\text{(}EF_R\text{ from Step 2E.4a(2))}}{\underline{\qquad\qquad}}$$

ER_R = _____ µg TSP/m-sec

(3) Now, calculate ER_{A+R}, the TSP emission rate for the convective-lift phase of your fire:

$$ER_{A+R} = \underset{\text{(}ER_A\text{ from Step 2E.5a(1))}}{\underline{\qquad\qquad}} + \underset{\text{(}ER_R\text{ from Step 2E.5a(2))}}{\underline{\qquad\qquad}}$$

ER_{A+R} = _____ µg TSP/m-sec

2E.5b Enter again in the ER_{CL} blank below the value of ER_{A+R} you just calculated in Step 2E.5a(3). Then enter in the ER_{NCL} blank the value of ER_R you calculated in Step 2E.5a(2).

ER_{CL} = _____ µg TSP/m-sec

ER_{NCL} = _____ µg TSP/m-sec.

2E.6 FIRING PATTERN AND FIRED-LINE LENGTH

2E.6a From your written prescription, enter here your prescribed primary firing pattern (check one, then go to indicated Steps):

Ring firing _____ (if checked, skip to Step 2E.6c)
Heading fire _____ (if checked, proceed to Step 2E.6b)

2E.6b Use planned length of fired line without further adjustment, entering length from your written prescription here:

_____ ft

Now skip directly to Step 2E.7.

2E.6c Determine an equivalent to fired line length by following the rule-of-thumb procedure outlined in the Southern Forestry Smoke Management Guidebook Chapter IV. Enter the equivalent determined here:

_____ ft

2E.7 HEAT RELEASE RATE

2E.7a Using the determined values from the Steps shown in the equation that follows, calculate the convective-lift phase heat release rate (HRR_{CL}) by performing the indicated multiplications. (Heat release is of negligible effect for the no-convective-lift phase.)

HRR_{CL} = 0.0012 x ____________ x ____________
(Available fuel from Step 2E.1d) (Rate of spread from Step 2E.2c)

x ____________ x ____________
(Consumption adjustment (y_A) from Step 2E.3a(1)) (Length of fired line from Step 2E.6b or or 2E.6c)

HRR_{CL} = _____ megacal/sec

NOW GO DIRECTLY TO STAGE #3

DECISION-LOGIC STAGE #3: LONG-RANGE MARGIN
You Have Been Directed Here from Stage #2

3.1 FUEL TYPE

3.1a Is the fuel type selected to describe your planned burn unpiled pine logging debris or palmetto-gallberry over 2 years old, or for other fuel types will your convective-lift fire phase last to a time 3 hours before sunset?

NO _____ (skip directly to Stage #4)
YES _____ (proceed to Step 3.2a)

3.2 DETERMINATION OF TOTAL EMISSION RATE, qL

3.2a Enter here again the length of fired line (or its equivalent if determined in Step 2E.6c):

L = _____ ft

Now convert this length in feet to length in meters (multiply feet by 0.3048), entering the converted length here:

L = _____ meters

3.2b Refer back to your Worksheet Set 2B or 2E for the value of ER_{NCL} (which equals q), entering this value again here (if ER_{NCL} not calculated, substitute ER_{CL}):
$q = ER_{NCL}$ = _____ μg TSP/m-sec

3.2c Multiply the entry for L *in meters* (not feet) from Step 3.2a times ER_{NCL} in Step 3.2b for a value of qL, entering the result here:

qL = _____ μg TSP/sec

3.3 SAFETY MARGIN

3.3a From your written prescription, enter here the transport windspeed:

_____ m/sec

3.3b (1) Using the metric value qL you entered in Step 3.2c and the transport windspeed you entered in 3.3a, refer to figure VI-M-1 to determine if the intersection of these two values is in the *safe* or *unsafe* portion of the graph.

If *safe*, it is likely your fire will not result in a long-range (>100 km or 62 miles) concentration greater than 150 $\mu g/m^3$. Which did you determine?

Safe _____ (skip directly to Stage #4)
Unsafe _____ (proceed to Step 3.3b(2))

3.3b (2) Because your long-range transport calculation indicates a risk that the concentration will exceed 150 $\mu g/m^3$ at or beyond 100 km (62 miles), you are redirected to Stage #1 to rewrite the prescription. *NOTE:* If possible, change time of burn for fuel types other than palmetto-gallberry or unpiled pine logging debris, or it may be desirable to modify the prescribed length of fired line or equivalent as a quick way of reducing the qL value, but bear in mind that this will also reduce the HRR_{CL} value with an effect on plume rise, considered later.

DECISION-LOGIC STAGE #4: MATCHING PRESCRIPTIONS TO TYPICAL CASES
You Have Been Directed Here from Stage #3

4.1 SELECTION OF TYPICAL CASE

4.1a To arrive at a set of easily used typical cases rather than an extremely large number of complex tables and computations, it has been necessary to fix certain variables. To use the procedure, you must now either conform your written prescriptions to at least equal those variables that are fixed or you must make a series of adjustments to the typical-case concentrations in order to match your burn situation. All adjustments and all prescribed elements that are more favorable to dispersion than typical will result in overestimates of tabular concentrations (i.e., the estimates are conservative).

NOTE: In this and all succeeding steps, complete no-convective-lift phase only for those burning situations for which you calculated an ER_{NCL} in Stage #2.

Turn now to table VI-M-1 to find the typical case (by fuel type) most closely matching yours, entering the case number here:

Convective-lift phase ________________
(Typical case no.)

No-convective-lift phase ________________
(Typical case no.)

4.2 MATCHING FIXED PRESCRIPTION ELEMENTS

4.2a In this Step, you will have a match to start with, will modify your prescription to match fixed variables, or will indicate a match cannot be made. For each of the following, enter your prescribed value:

Convective-lift phase[6]: Stability class _____
Mixing height _____m

No-convective-lift phase: Stability class _____
Mixing height _____m

4.2b For each of the following, indicate which answer applies.

(1) Column 2: Stability class must be at least as good as shown in table VI-M-I.[7] Indicate how your prescription matches (check one in each phase):

---

[6]For actual day of burn, if National Weather Service is not furnishing stability class, see Southern Forestry Smoke Management Guidebook Chapter V for a method of determining stability class in the field.

[7]Note stability classes decrease in ability to help smoke dispersion as these scale from A to D (i.e., A is better than B, etc.). Classes shown as typical are more likely to be encountered.

	Convective-lift phase	No-convective-lift phase
Matched or is better	_____	_____
Made to match	_____	_____
Is not as good as and cannot be made to match	_____	_____

(2) Column 3: Mixing height must be higher than or at least within 300 meters of the value shown as typical in table VI-M-1. Indicate how your prescription matches (check one in each phase):

	Convective-lift phase	No-convective-lift phase
Matched or is better	_____	_____
Made to match	_____	_____
Is not as good as and cannot be made to match	_____	_____

4.2c In both (1) and (2) of Step 4.2b, did you check that a match could be made? (check only one):

YES (both matched or made to match) _____

Skip to Step 4.3a

NO (one or both variables cannot be made to match) _____

If a match cannot be made, we recommend that you arrange for a computer-assisted analysis for determining the best combination of prescription elements. Is this possible?

YES _____ (If this is possible, proceed directly to Stage #6)

NO _____ (If not possible, you will run a risk of causing or contributing to a pollution episode under your present prescription. An alternative to burning is recommended.)

4.3 OTHER VARIABLES AND CORRECTION FACTORS

4.3a Each of the following variables can be made to match the typical case by correction factors. First enter here for subsequent use the values shown in your written prescription for transport windspeed:

Convective-lift phase _____m/sec   No-convective-lift phase _____m/sec

4.3b Now enter the crosswind length of fired line from your prescription. (*NOTE*: Do not use the fired-line equivalent for logging debris from Step 2E.6c here. For this calculation, the crosswind width of the fired area is needed in order to arrive at plume width.)

(1) _____ ft

And then convert this value to meters by multiplying feet by 0.3048, entering the conversion here:

(2) _____ m

4.3c Enter here values from that portion of Stage #2 you completed:

(1) Convective-lift phase heat release rate
HRR_{CL} _____ megacal/sec

(2) Emission rates (ER)
ER_{CL} _____ µg/m-sec

ER_{NCL} _____ µg/m-sec

4.3d In this Step, you will derive individual correction factors for each of the above variables by comparing your entries with typical values in table VI-M-1. (These will be used to the nearest 1/10th in Step 4.4a to develop a single correction factor.)

(1) TRANSPORT WINDSPEED. Calculate a correction factor for transport windspeed by dividing the table VI-M-1 typical-case value by the value you entered in Step 4.3a, entering the result here (if values are equal, enter 1.0):

Convective-lift phase _____ No-convective-lift phase _____

(2) HEAT RELEASE RATE. Is the heat release rate (HRR_{CL}) you entered in Step 4.3c equal to or greater than the table VI-M-1 column #4 typical case? (check one):

If YES, $\geq$ _____, enter 1.0 below

If NO, < _____, enter a worst-case correction factor of 1.4 below

Correction factor _____

(3) CONVECTIVE-LIFT PHASE EMISSION RATE. Calculate a correction factor for convective-lift phase emission rate (ER_{CL}) by dividing your ER_{CL} from Stage #2 by the table VI-M-1 typical case ER_{CL}, entering the result here (if your ER_{CL} is the same as the typical case ER_{CL}, enter 1.0):

Correction factor = $\underset{(\text{Stage \#2 } ER_{CL})}{\underline{\hspace{3cm}}} \div \underset{(\text{Typical } ER_{CL})}{\underline{\hspace{3cm}}} = $ _____

(4) NO-CONVECTIVE-LIFT PHASE EMISSION RATE. Calculate a correction factor for the no-convective-lift phase emission rate (ER_{NCL}) by dividing your ER_{NCL} from Stage #2 by the table VI-M-1 typical case ER_{NCL}, entering the result here (if your ER_{NCL} is the same as the typical case ER_{NCL}, enter 1.0):

Correction factor = __________ (Stage #2 ER_{NCL}) ÷ __________ (Typical ER_{NCL}) = ______

(5) FIRED-LINE LENGTH. Is the crosswind length of fired line in Step 4.3b(2) less than or equal to the table VI-M-1 column #5 typical-case length?

If YES, check here then enter 1.0 for a correction factor for all distances in the spaces below ______

If NO, check here then turn to table VI-M-6 and list in the spaces below the given correction factors for each distance ______

Downwind Distances (km)	(miles)	: Crosswind fired-line length correction factors (nearest 1/10th)
0.10	.06	________
.13	.08	________
.16	.10	________
.20	.12	________
.25	.16	________
.32	.20	________
.40	.25	________
.50	.31	________
.63	.39	________
.79	.49	________
1.00	.62	________
1.30	.81	________
1.60	.99	________
2.00	1.24	________
2.50	1.55	________
3.20	2.00	________
4.00	2.50	________
5.00	3.11	________
6.30	3.92	________
7.90	4.91	________
10.00	6.21	________
13.00	8.08	________
16.00	9.94	________
20.00	12.43	________
25.00	15.53	________
32.00	19.88	________
40.00	24.86	________
50.00	31.07	________
63.00	39.15	________
79.00	49.09	________
100.00	62.14	________

4.4 COMBINING CORRECTION FACTORS AND MAKING CORRECTIONS

4.4a Now calculate combined correction factors (nearest 1/10th) to be used at each distance for each fire phase as follows:

(1) Enter here and multiply the following convective-lift phase factors:

________	x	________	x	________	=	________
(Transport windspeed factor from Step 4.3d(1))		(HRR_{CL} factor from Step 4.3d(2))		(ER_{CL} factor from Step Step 4.3d(3))		(Result, CL phase)

Then use the convective-lift phase multiplication result immediately above to multiply *each* line-length correction factor listed in Step 4.3d(5), entering the final multiplication result in column (B) of the blank table that follows Step 4.4b.

(2) If you are carrying forward a no-convective-lift phase, enter here and multiply the following no-convective-lift factors:

____________	x	____________	=	____________
(Transport windspeed factor from Step 4.3d(1))		(ER_{NCL} factor from Step 4.3d(4))		(Result, NCL phase)

Then use the no-convective-lift phase multiplication result immediately above to again multiply *each* line-length correction factor listed in Step 4.3d(5), entering the final multiplication result in column (D) of the blank table which follows Step 4.4b.

4.4b Use the same typical-case numbers you entered in Step 4.1a to again refer to table VI-M-1, column 8, for the appropriate concentration tables to use next. Enter here the tables to be used.

Convective-lift-phase concentration table VI-M-____

No-convective-lift phase concentration table VI-M-____

Next use the concentration tables you just selected as follows for the worktable immediately below:

(1) Opposite each distance, and in the column that fits your burning situation, read the typical-case concentration, entering it in column (C) for convective-lift phase, or in column (E) for no-convective-lift phase of the worktable which follows.

(2) Now multiply each typical-case concentration entry in the following worktable by its correction factor, and enter the result in the corrected concentration columns, (C') (E'), for convective-lift and no-convective-lift phases, respectively, in the worktable.

(A) Downwind distances (km)	(A) Downwind distances (miles)	Convective-lift phase (B) Correction factor	Convective-lift phase (C) Typical-case concentration	Convective-lift phase (C') Corrected concentration	No-convective-lift phase[1] (D) Correction factor	No-convective-lift phase[1] (E) Typical-case concentration	No-convective-lift phase[1] (E') Corrected concentration
0.10	.06						
.13	.08						
.16	.10						
.20	.12						
.25	.16						
.32	.20						
.40	.25						
.50	.31						
.63	.39						
.79	.49						
1.00	.62						
1.30	.81						
1.60	.99						
2.00	1.24						
2.50	1.55						
3.20	2.00						
4.00	2.50						
5.00	3.11						
6.30	3.92						
7.90	4.91						
10.00	6.21						
13.00	8.08						
16.00	9.94						
20.00	12.43						
25.00	15.53						
32.00	19.88						
40.00	24.86						
50.00	31.07						
63.00	39.15						
79.00	49.09						
100.00	62.14						

[1]Complete only for those burning situations where you calculated an ER_{NCL} for the no-convective-lift phase in Section 2.

NOW PROCEED TO STAGE #5.

DECISION-LOGIC STAGE #5: PLOTS OF CONCENTRATION, COMPARISONS, MODIFICATIONS, AND MULTIPLE-SOURCE ANALYSIS

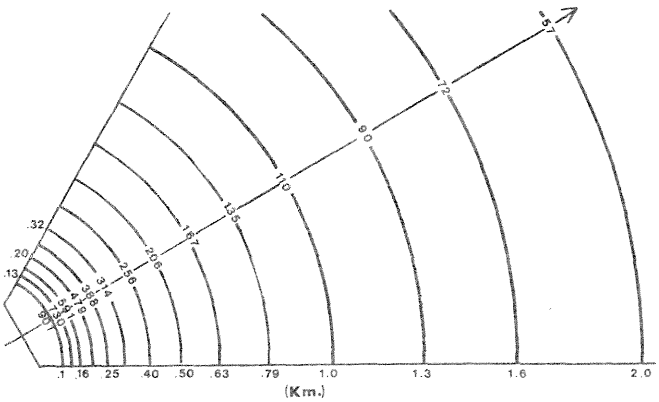
5.1 PLOTTING ZONES OF CONCENTRATION

5.1a Using a drawing compass, set it to scale for each distance in Column (A) of the Worktable you just completed in Step 4.4b, and strike distance arcs on the trajectory plots you made on the map in Steps 1.1(1) and (2) as follows:

Until the distance from the fire is twice the length of the fired line, strike two arcs--one centered at each end of the fired line--then connect them by a straight line parallel to the fired line. After the distance from the fire is twice the fired-line length, strike only one arc centered at the intersection of the fired line with the plume centerline.

NOTE: If target backgrounds are low and multiple fires are not expected, you need to plot arcs only to the distances where your corrected concentrations (Step 4.4b, Columns (C') and (E')) will be of importance. If important distances are within 2 kilometers, a plot on a separate, large-scale map will be desirable.

5.1b Now use the same two colors for the combustion stages that you used in Step 1.1a to write the corrected concentrations from the Worktable in Step 4.4b on your map at each corresponding distance arc. A completed trajectory plot with zones on concentration will look like this:



5.2 COMPARING CRITICAL TARGET ACCEPTABLE CONCENTRATIONS WITH PREDICTED TOTAL CONCENTRATIONS

5.2a Starting in the map area with the highest zone of concentration and working toward zones of lower concentrations, select the most critical targets expected to experience the concentrations plotted. List these selected targets one at a time in Column (A) of the Worktable immediately below, entering the corresponding values the table calls for at the time you list each target. The following instructions apply to determining values for entries called for by the Worktable.

Column (B) - Applicable Smoke Concentration Zone Value.--For targets directly on an arc, use the concentration zone value shown with the arc. For targets falling between two arcs, always use the higher of the two concentrations unless you interpolate logarithmically.

Column (C) - Expected Background Concentration at Target.--Entries in this column must be for the time of year for which a planned burn prescription is being applied to this logic procedure or must be actual These can be obtained, in some cases, from air quality personnel; or lacking this help, a rule of thumb will give you an expected particulate matter concentration based upon the expected visibility (which can be drawn from experience, airport climatological records, or local residents). It is based upon the relationship:

730 μg-miles/m^3 ÷ miles of visibility = TSP concentration in μg/m^3.

Some typical values are:

25-mile visibility = 29 μg/m^3; 20-mile visibility = 36 μg/m^3;
15-mile visibility = 49 μg/m^3; 10-mile visibility = 73 μg/m^3;
5-mile visibility =146 μg/m^3; 2-mile visibility =365 μg/m^3.

Column (D) - Predicted Total Concentration.--The entry for this column is simply the sum of the value entered in Column (B) and the value entered in Column (C).

Column (E) - Maximum Acceptable Concentration.--This entry is best obtained from local air quality personnel. Lacking this help, it is suggested you use a visibility criterion and the same rule of thumb as was suggested in the Column (C) instructions above. In this case, you set the minimum visibility you believe will be acceptable (*CAUTION*: This is reportedly rarely less than 5 miles), then enter the corresponding concentration. EXAMPLE: 10-mile visibility is believed to be the minimum below which public complaints will be raised; then the corresponding maximum acceptable concentration entry is 73 μg/m^3, (730 ÷ 10).

WORKTABLE

(A) Target name or other identifier	(B) Applicable smoke concentration zone value CL phase : NCL phase	(C) Expected background concentration at target	(D) Predicted total concentration Col. (B) + Col. (C) CL phase : NCL phase	(E) Maximum acceptable concentration

5.2b Now compare the Column (E) entries with both the convective-lift and no-convective-lift phase entries in Column (D).

Is the predicted total concentration less than the maximum acceptable concentration for all entries? (check for each phase)

Convective-lift phase	No-convective-lift phase
Yes ______	Yes ______
No ______	No ______
	Not applicable ______

5.2c (1) If you checked YES for applicable phases above and do not anticipate that other burns may contribute to concentrations in target areas, check here and STOP using logic at this point. PROCEED WITH YOUR BURN.

______

(2) If you checked YES for applicable phases above but anticipate other prescribed burns may contribute to concentrations in target areas and want to run a further analysis, check here and skip to Step 5.4.

______

OR, if you do not want to skip to Step 5.4 check here and STOP using logic.

______

PROCEED WITH YOUR BURN ONLY IF YOU WANT TO RISK POSSIBLE TARGET-AREA CONCENTRATIONS IN EXCESS OF DESIRED NET.

(3) If you checked NO in either phase, proceed to Step 5.3.

5.3 DETERMINING WHICH PRESCRIPTION VARIABLES TO MODIFY

5.3a Look back to the Worktable you completed in Step 5.2a for the worst case (i.e.: greatest amount Column (D) exceeds Column (E)).

Now divide the Column (D) entry by the Column (E) entry, entering the result of division here:

______

(1) If the result of division is less than 2, your chance of making a desk-top revision of your prescription for an acceptable concentration is good. Check here and skip directly to Step 5.3b.

______

(2) If the result of division is less than 5, there is a chance of making an acceptable revision of your prescription--but repeated trials are likely to be needed, and a Stage #6 analysis will be most desirable.

If you can arrange for assistance with a Stage #6 automatic data processing analysis, check here and STOP further work on Phase #5.

______

If you cannot arrange for assistance, you may elect to try a desk-top revision and should skip directly to Step 5.3b after checking here.

______

If you cannot arrange for assistance and do not elect to try a desk-top revision, skip directly to Step 5.3g after checking here.

______

(3) If the result of division is greater than 5, skip directly to Step 5.3g after checking here.

______

5.3b If your prescription calls for a heading fire, first consider revising the prescription to call for a backing fire. Check here, then proceed to Step 5.3c BEFORE modifying your prescription.

______

5.3c Examine the correction factors you calculated in Stage #4, entering a check here for each that is greater than 1.0.

Variable	Calculated in Step	Convective-lift phase factor (√)	No-convective-lift phase factor (√)
Transport windspeed	4.3d(1)		
Length of fired line	4.3d(2)		
HRR_{CL}	4.3d(3)		Not applicable
ER_{CL}	4.3d(4)		Not applicable
ER_{NCL}	4.3d(5)		

5.3d If any of the above checked factors include transport windspeed and/or fired-line length factors, you will next want to modify your prescription to lower these. The fired-line length correction factor is lowered by shortening the prescribed fired-line length. The transport windspeed correction factor is lowered by increasing the prescribed speed. NOTE: For this analysis, it will not benefit your calculations to reduce the fired-line length below that used in the typical case (see table VI-M-1). Check here, then proceed to Step 5.3e BEFORE modifying your prescription.

______

5.3e If your exceeded allowable concentration is only in the convective-lift phase and your heat release rate correction factor is checked in Step 5.3c, this is the next prescription item to consider modifying. Before deciding to do so, make sure the emission rate correction factor IS NOT also checked. HRR_{CL} is best increased, resulting in a lower correction factor, by increasing rate of spread (which is a function of lower fine fuel moisture and higher surface windspeed). These, however, will all increase emission rate, which can offset your gains. Check here and then proceed to Step 5.3f BEFORE modifying your prescription.

5.3f Now, having considered the instructions in Steps 5.3b through 5.3e, list here any variables you intend to modify in your prescription. Then use a colored pencil to enter new values in the prescription and in the preceding Stages #2 through #5, Steps 5.1 and 5.2, reworking all dependent calculations and comparisons until you have again arrived at Step 5.3. If there are no variables that can be modified, enter NONE, then proceed to Step 5.3g.

Variables to be modified

____

____

____

____

CAUTION: Do not simply modify the prescription and then use new correction factors in Stage #4. Many of the variables are interdependent, resulting in offsetting changes. Hopefully, after reworking Stages #2 through #4 and Steps 5.1 and 5.2, you will be able to skip to Step 5.3 on the next pass through!

5.3g You have arrived at this Step either because of too great a difference between predicted total concentration and maximum acceptable concentration, or because of computational difficulties that cannot be remedied.

If this is the case, you may wish to consider exploring exceeded maximum acceptable concentrations at some targets for a very short time period. By limiting the dimension of the burn area which is on the same azimuth as the transport wind direction, the duration is limited. For example: Wind at right angle to road. A 200-foot-wide burned area will at least provide a good fuel break. If instead of burning the entire tract you burn to a 200-foot limit, the time of high smoke concentration will be shortened and you may be able to work with local authorities to provide traffic control for safety on the road for the short period this size burn would take to burn out. Other than this, you may need to select a treatment alternative other than fire.

Enter your decision here and STOP using the logic procedure:

____

____

____

5.4 RUDIMENTARY MULTIPLE-SOURCE ANALYSIS

5.4a This Step is for conducting a rudimentary multiple-source analysis if there is a likelihood that more than your prescribed burn will contribute to target concentrations.

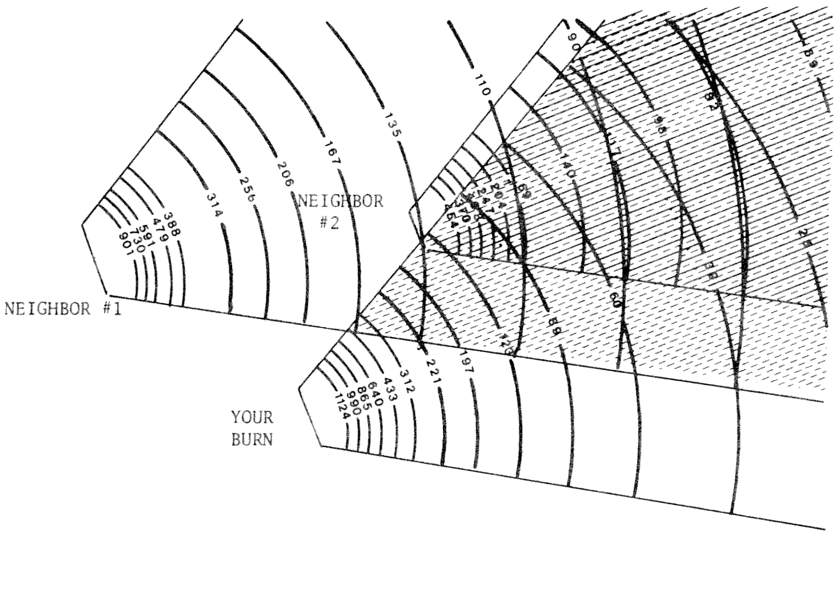
For all such suspect simultaneous sources, follow this procedure:

(1) For each, plot the trajectory and 30° deviations as you did in Steps 1.1a (1) and (2).

(2) For all those where the 30° deviations overlap with those from this burn, it will be most desirable to have available completed, separate analyses such as this. If not available, use either the final trajectory plots from Step 5.1b of this burn again, or simply use the unadjusted values from a typical case (see table VI-M-1 and corresponding tables), whichever comes closest.

(3) With the new burn trajectory(s) plotted to show arcs as zones of concentration, as you did for this burn, you can now sum the zones in all overlapping areas to prepare a mutual targets worktable in the same format as you did in Step 5.2a for this burn alone.

EXAMPLE:



In this example, the applicable concentration zone values, relating two neighbors' burns to your burn, become:

Your burn alone	Your burn and neighbor #1	All three burns
1,124		
990		
865		
640		
433	433 + 167	
312	312 + 167	
221	221 + 167	
221	221 + 135	
197	197 + 167	
197	197 + 135	
123	123 + 135	123 + 135 + 454
123	123 + 135	123 + 135 + 370
123	123 + 135	123 + 135 + 303
123	123 + 135	123 + 135 + 247
123	123 + 135	123 + 135 + 204
88	88 + 135	88 + 135 + 204
88	88 + 135	88 + 135 + 169
88	88 + 110	88 + 110 + 169
88	88 + 110	88 + 110 + 140
60	60 + 110	60 + 110 + 169
60	60 + 110	60 + 110 + 140
60	60 + 110	60 + 110 + 117
60	60 + 90	60 + 90 + 117
60	60 + 90	60 + 90 + 98
39	39 + 90	39 + 90 + 117
39	39 + 90	39 + 90 + 98
39	39 + 82	39 + 82 + 82
25	25 + 82	25 + 82 + 90
25	25 + 82	25 + 82 + 82
25	25 + 82	25 + 82 + 69

DECISION-LOGIC STAGE #6: AUTOMATIC DATA PROCESSING ASSISTED ANALYSIS

This Stage is under development at this time and will be issued later. The following is a brief outline of what is planned:

1. *A program in FORTRAN for use on any compatible computer.*--This program will be printed as a "separate" that can be inserted into copies of the Sourcebook. With the program, rapid reiterations of combinations of variables now made by hand in Stages #2 through #5 will be possible. Hence, the user will be able to quickly select the best of his prescription options. Instructions for use will also be printed as a "separate" that can be inserted into copies of the Guidebook.

2. *An adaptation of the above program for use in a central computer.*--Data from spot weather forecasts would be entered, along with user inputs to determine likely downwind concentrations.

3. *A refined system for analyzing the effects of multiple forestry emissions sources on air quality.*

PART 3. TABLES

The tables that follow are for use with the Steps in the preceding instructions. Sources of these tables are discussed in preceding chapters—fuel and fire behavior tables (VI-F-1 through VI-F-13, printed on pink paper) in Chapter IV and meteorology tables and figure (tables VI-M-1 through VI-M-6 and fig. VI-M-1 printed on blue paper) in Chapter V. For the convenience of users and to permit periodic updating, each table is presented on a separate page.

Table VI-F-1. — Effect of age of rough on total available grass accumulations under pine overstories

Age of rough (years)	Total available grass accumulation
	Tons per acre
1	1.86
2	1.00
3	.71
4	.57
5	.48
10	.31
15	.26
20	.23
25	.21

Table VI-F-2. — Fine fuel moisture content of dead grass (1-hour timelag)

Cloud cover and dry bulb temperature 1/ (°F)	Relative humidity									
	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65-69	70-74
	Percent									
Sunny:										
10-29	5	5	6	7	8	8	8	9	9	10
30-49	5	5	6	7	7	7	8	9	9	10
50-69	5	5	6	6	7	7	8	8	9	9
70-89	4	5	5	6	7	7	8	8	8	9
Cloudy:										
10-29	6	7	8	9	10	11	12	12	14	15
30-49	6	7	8	9	9	11	11	12	13	14
50-69	6	6	8	8	9	10	11	11	12	14
70-89	5	6	7	8	9	10	10	11	12	13

1/Adapted from Deeming and others (1972).

Purpose. — To compute the fine fuel moisture content of dead grass 0.25 inch and less in diameter.

Procedure. — Use "cloudy" if there is 60 to 90 percent cloud cover; an overcast covering more than 90 percent of the sky; fog, showers, or thunderstorms in the vicinity; or if the observation is being taken before 10:00 a.m. or after 3:00 p.m. local standard time. "Sunny" covers all other conditions.

Table VI-F-3.— Moisture content of pine needle litter [1/]

Relative humidity (percent)	Moisture content
	Percent
25 to 29	8
30 to 34	8
35 to 39	9
40 to 44	9
45 to 49	10
50 to 54	11
55 to 59	12
60 to 64	13
65 to 69	15
70 to 74	17

1/ Based on Blackmarr (1971).

Table VI-F-4. — Expected rate of fire spread in grass fuels 1/ 2/ as a function of midflame windspeed and fine fuel moisture content where land slopes do not exceed 20 percent

Midflame windspeed 3/ (miles per hour)	Rate of spread — Fine fuel moisture (percent)					
	4	6	8	12	16	20
			Feet per minute			
0	5	4	4	3	3	2
1	11	9	8	6	6	5
2	25	21	18	14	13	11
3	45	37	32	26	23	19
4	71	59	50	41	36	30
5	101	84	72	59	51	43
6	137	114	98	79	69	58

1/ Adapted from Rothermel (1972).

2/ Factors used in Rothermel's (1972) equation:

$W_o = 0.088$ lb/ft^2 MCE = 30

d = 1.0 WS = 0, 1, 2, 3, 4, 5, 6

s/v = 2,500 MC = 4, 6, 8, 12, 16, 20

mc = 0.0555 HV = 8,000

sc = 0.01 DEN = 32

3/ Under a tree canopy, midflame windspeed can be estimated by using windspeed values from the nearest 20-foot, open-tower installation and dividing that value by 4.

Table VI-F-5. — Total litter weight under slash pine stands as affected by stand basal area and age of rough 1/

Stand basal area (square feet per acre)	Age of rough (years)								
	1	2	3	4	5	7	10	15	20
	Tons per acre								
30	1.5	2.5	3.4	4.2	4.8	5.9	7.0	8.1	8.4
50	1.6	2.8	3.8	4.7	5.4	6.6	7.9	9.0	9.4
70	1.8	3.2	4.3	5.2	6.1	7.4	8.8	10.1	10.5
90	2.1	3.5	4.8	5.9	6.8	8.3	9.9	11.3	11.7
110	2.3	4.0	5.4	6.6	7.6	9.3	11.1	12.7	13.2
130	2.6	4.4	6.0	7.3	8.5	10.4	12.4	14.2	14.7
150	2.9	5.0	6.7	8.2	9.5	11.6	13.9	15.9	16.5
175	3.3	5.7	7.7	9.5	11.0	13.4	16.0	18.3	19.0
200	3.8	6.6	8.9	10.9	12.6	15.4	18.4	21.1	21.9

1/ Applies to stands with or without understory vegetation (McNab and Edwards 1976).

Table VI-F-6. — Total litter weight under loblolly pine stands as affected by stand basal area and age of rough

Stand basal area (square feet per acre)	Age of rough (years)							
	1	2	3	4	5	7	10	15
	Tons per acre							
30	1.4	2.2	2.9	3.4	3.8	4.5	4.7	4.7
50	1.5	2.4	3.2	3.9	4.3	5.0	5.3	5.3
70	1.6	2.8	3.7	4.3	4.8	5.6	5.9	5.9
90	1.9	3.0	4.1	4.8	5.4	6.3	6.6	6.6
110	2.1	3.5	4.6	5.4	6.0	7.1	7.4	7.4
130	2.4	3.8	5.1	6.0	6.7	7.9	8.3	8.3
150	2.7	4.3	5.7	6.7	7.5	8.8	9.3	9.3
175	3.0	5.0	6.6	7.8	8.7	10.2	10.7	10.7
200	3.5	5.8	7.6	8.9	10.0	11.7	12.3	12.3

Table VI-F-7. — Estimated available litter fuel weights for different total litter weights and moisture contents 1/

Total litter weight (tons per acre)	Total litter layer moisture content (percent)										
	10	20	40	60	80	100	120	140	160	180	200
	Tons per acre										
2	1.2	1.0	0.5	—	—	—	—	—	—	—	—
4	3.4	3.1	2.7	2.2	1.7	1.2	0.8	0.3	—	—	—
6	4.6	4.4	3.9	3.4	3.0	2.5	2.0	1.5	1.1	0.6	0.1
8	5.6	5.4	4.9	4.4	4.0	3.5	3.0	2.5	2.1	1.6	1.1
10	6.5	6.3	5.8	5.3	4.9	4.4	3.9	3.4	3.0	2.5	2.0
12	7.4	7.1	6.7	6.2	5.7	5.2	4.8	4.3	3.8	3.3	2.8
14	8.2	8.0	7.5	7.0	6.6	6.1	5.6	5.1	4.7	4.2	3.7
16	9.0	8.8	8.3	7.8	7.4	6.9	6.4	5.9	5.5	5.0	4.5

1/ Based on unpublished data on file at the Southern Forest Fire Laboratory, Southeastern Forest Experiment Station, USDA Forest Service, Macon, Ga.

Table VI-F-8. — Expected rate of fire spread in pine needle and low brush fuels 1/ 2/ as a function of midflame windspeed and pine needle litter moisture content where land slopes do not exceed 20 percent

Midflame windspeed 3/ (miles per hour)	Rate of spread				
	Pine needle litter moisture content (percent)				
	6	8	12	16	20
	Feet per minute				
0	1	1	1	1	1
1	2	2	2	1	1
2	5	4	3	3	2
3	7	6	5	4	4
4	10	9	7	6	5
5	13	11	9	8	7
6	16	14	11	10	8

1/ Adapted from Rothermel (1972).
2/ Factors used in Rothermel's (1972) equation:

W_o = 1.25 ton/acre = 0.057 lb/ft^2

d = 0.25 (3 inches)

s/v = 1,500

mc = 0.04 (min. content)

sc = 0.01

MCE = 0.40

WS = 0, 1, 2, 3, 4, 5, 6

MC = 6, 8, 12, 16, 20

HV = 8,000

DEN = 26

3/ Under a tree canopy, midflame windspeed can be estimated by using windspeed values from the nearest 20-foot, open-tower installation and dividing that value by 4.

Table VI-F-9. — Understory vegetative dry weight in the palmetto-gallberry type as related to age of rough and understory height

Understory height (feet)	Age of rough (years)							
	1	2	3	5	7	10	15	20
	Tons per acre							
1	0.4	0.4	0.5	0.6	0.9	1.4	2.6 1/	4.2 1/
2	1.2	1.3	1.3	1.5	1.7	2.2	3.4 1/	5.1 1/
3	2.6	2.6	2.7	2.8	3.1	3.5	4.7	6.4
4	4.5 1/	4.5	4.6	4.7	5.0	5.5	6.6	8.3
5	7.0 1/	7.0 1/	7.0	7.2	7.4	7.9	9.1	10.8
6	10.0 1/	10.0 1/	10.0 1/	10.2	10.4	10.9	12.1	13.8

1/ Represents a situation not likely to be found in nature.

Table VI-F-10. — Estimated total available fuel (litter + vegetation) as a function of total litter layer moisture content, total litter weight, and understory vegetative dry weight

Understory vegetative dry weight (tons per acre)	Total available fuel (litter + vegetation)										
	Total litter weight in tons per acre										
	1	2	3	4	5	6	8	10	12	14	16
	Tons per acre										
10 PERCENT TOTAL LITTER LAYER MOISTURE CONTENT											
1	0.0	2.0	3.2	4.1	4.8	5.4	6.5	7.5	8.4	9.3	10.2
3	.4	3.3	4.6	5.5	6.1	6.7	7.8	8.8	9.8	10.7	11.6
5	1.7	4.7	5.9	6.8	7.5	8.1	9.2	10.2	11.1	12.0	12.9
7	3.1	6.0	7.3	8.2	8.8	9.4	10.5	11.5	12.5	13.4	14.3
9	4.4	7.4	8.7	9.5	10.2	10.8	11.9	12.9	13.8	14.7	15.6
11	5.8	8.7	10.0	10.9	11.5	12.2	13.2	14.2	15.2	16.1	17.0
20 PERCENT TOTAL LITTER LAYER MOISTURE CONTENT											
1	0.0	1.7	3.0	3.8	4.5	5.1	6.2	7.2	8.1	9.1	10.0
3	.1	3.0	4.3	5.2	5.9	6.5	7.5	8.5	9.5	10.4	11.3
5	1.4	4.4	5.7	6.5	7.2	7.8	8.9	9.9	10.8	11.8	12.7
7	2.8	5.7	7.0	7.9	8.6	9.2	10.2	11.2	12.2	13.1	14.0
9	4.1	7.1	8.4	9.2	9.9	10.5	11.6	12.6	13.5	14.5	15.4
11	5.5	8.5	9.7	10.6	11.3	11.9	13.0	13.9	14.9	15.8	16.7
40 PERCENT TOTAL LITTER LAYER MOISTURE CONTENT											
1	0.0	1.1	2.4	3.3	4.0	4.6	5.6	6.6	7.6	8.5	9.4
3	.0	2.5	3.8	4.6	5.3	5.9	7.0	8.0	8.9	9.9	10.8
5	.9	3.8	5.1	6.0	6.7	7.3	8.3	9.3	10.3	11.2	12.1
7	2.2	5.2	6.5	7.3	8.0	8.6	9.7	10.7	11.6	12.6	13.5
9	3.6	6.5	7.8	8.7	9.4	10.0	11.0	12.0	13.0	13.9	14.8
11	4.9	7.9	9.2	10.0	10.7	11.3	12.4	13.4	14.3	15.3	16.2
80 PERCENT TOTAL LITTER LAYER MOISTURE CONTENT											
1	0.0	0.0	1.3	2.2	2.9	3.5	4.5	5.5	6.5	7.4	8.3
3	.0	1.4	2.7	3.5	4.2	4.8	5.9	6.9	7.8	8.8	9.7
5	.0	2.7	4.0	4.9	5.6	6.2	7.2	8.2	9.2	10.1	11.0
7	1.1	4.1	5.4	6.2	6.9	7.5	8.6	9.6	10.5	11.5	12.4
9	2.5	5.4	6.7	7.6	8.3	8.9	9.9	10.9	11.9	12.8	13.7
11	3.8	6.8	8.1	8.9	9.6	10.2	11.3	12.3	13.2	14.2	15.1
120 PERCENT TOTAL LITTER LAYER MOISTURE CONTENT											
1	0.0	0.0	0.2	1.1	1.8	2.4	3.4	4.4	5.4	6.3	7.2
3	.0	.3	1.6	2.4	3.1	3.7	4.8	5.8	6.7	7.6	8.6
5	.0	1.6	2.9	3.8	4.5	5.1	6.1	7.1	8.1	9.0	9.9
7	.0	3.0	4.3	5.1	5.8	6.4	7.5	8.5	9.4	10.4	11.3
9	1.4	4.3	5.6	6.5	7.2	7.8	8.8	9.8	10.8	11.7	12.6
11	2.7	5.7	7.0	7.8	8.5	9.1	10.2	11.2	12.1	13.1	14.0
160 PERCENT TOTAL LITTER LAYER MOISTURE CONTENT											
1	0.0	0.0	0.0	0.0	0.6	1.3	2.3	3.3	4.3	5.2	6.1
3	.0	.0	.5	1.3	2.0	2.6	3.7	4.7	5.6	6.5	7.5
5	.0	.5	1.8	2.7	3.4	4.0	5.0	6.0	7.0	7.9	8.8
7	.0	1.9	3.2	4.0	4.7	5.3	6.4	7.4	8.3	9.3	10.2
9	.3	3.2	4.5	5.4	6.1	6.7	7.7	8.7	9.7	10.6	11.5
11	1.6	4.6	5.9	6.7	7.4	8.0	9.1	10.1	11.0	12.0	12.9

Table VI-F-11. — Expected rate of fire spread 1/ in palmetto-gallberry fuels as a function of midflame windspeed and pine needle litter moisture content where land slopes do not exceed 20 percent

Midflame windspeed 2/ (miles per hour)	Rate of spread				
	Pine needle litter moisture content (percent)				
	6	8	12	16	20
	Feet per minute				
0	3	2	2	2	2
1	6	5	5	4	4
2	12	11	10	9	8
3	20	19	17	15	13
4	30	28	25	22	20
5	42	38	33	31	27
6	54	49	44	39	35
7	67	61	54	49	44

1/ Adapted from Hough and Albini (1976).

2/ Under a tree canopy, midflame windspeed can be estimated by using windspeed values from the nearest 20-foot, open-tower installation and dividing that value by 4.

Table VI-F-12. — Available fuel 1 inch in diameter and less in the unpiled pine logging debris type

Average d.b.h. in cut stand (inches)	Undisturbed logging residue	
	Loblolly	Slash
	---- Tons per cord cut ----	
5	—	0.47
6	0.20	.30
7	.17	.24
8	.15	.21
9	.13	.21
10	.11	.23
11	.12	.28
12	.13	—
14	.11	—
16	.10	—

Table VI-F-13. — Expected rate of fire spread in broadcast southern pine logging debris (Fuel Model C) 1/ as a function of midflame windspeed and pine needle litter moisture content where land slopes do not exceed 20 percent

Midflame windspeed 2/ (miles per hour)	Rate of spread				
	Pine needle litter moisture content (percent)				
	6	8	12	16	20
	Feet per minute				
0	3	2	2	1	1
1	4	4	4	3	3
2	10	8	7	6	4
3	16	15	12	10	7
4	30	24	18	15	12
5	36	30	24	21	18
6	48	42	36	30	24
7	66	60	48	42	30
8	78	72	60	48	36
9	102	90	72	60	42
10	120	102	90	72	54

1/ National Fire-Danger Rating System classification adapted.

2/ Since this fuel type is not under a tree canopy, midflame windspeed can be estimated by using windspeed values from the nearest 20-foot, open-tower installation and dividing that value by 2.

Table VI-M-1. — Summary of variables used in compiling typical case examples in tables VI-M-2 through VI-M-5

Typical case no.	1 Typical for	2 Pasquill stability class	3 Mixing height	4 Heat release rate (HRR)	5 Length of fired line or equiv.	6 Transport windspeed	7 Emission rate (ER)	8 See concentration in table
			Meters	Megacal/sec	Meters	M/sec	μg/M-sec	
1	Grass: Backing fire	C	1,500	14.112	800	8	37,800	VI-M-2
2	Grass: Heading fire	C	1,500	75.624	400	8	403,200	VI-M-2
3	Pine needle litter: Backing fire	C	1,500	4.704	400	8	84,000	VI-M-3
4	Pine needle litter: Heading fire							
	CL phase	C	1,500	11.76	400	8	966,000	VI-M-3
	NCL phase	C	1,500	0	400	8	756,000	VI-M-3
5	Palmetto-gallberry: Backing fire	C	1,500	37.632	800	8	168,000	VI-M-4
6	Palmetto-gallberry: Heading fire in 2-year-old rough	C	1,500	137.984	800	8	616,000	VI-M-4
7	Pine logging debris: In winter							
	CL phase	C	1,500	211.68	500 (eq.)	8	5,745,600	VI-M-5
	NCL phase	C	1,500	0	500 (eq.)	8	3,628,800	VI-M-5
8	Pine logging debris: In summer							
	CL phase	B	2,000	70.56	500 (eq.)	5	1,915,200	VI-M-5
	NCL phase	B	2,000	0	500 (eq.)	5	1,209,600	VI-M-5

Table VI-M-2. — Particulate matter concentrations at various distances downwind for typical cases No. 1 and No. 2

Distance downwind X (km)	Concentration (X)	
	Backing fire	Heading fire
	$\mu g/m^3$	$\mu g/m^3$
0.10	203	2,161
.13	164	1,751
.16	133	1,481
.20	108	1,149
.25	87	931
.32	71	754
.40	58	611
.50	47	495
.63	39	400
.79	31	319
1.00	26	249
1.30	21	188
1.60	18	138
2.00	17	98
2.50	15	68
3.20	12	47
4.00	10	33
5.00	8	24
6.30	5	19
7.90	4	15
10.00	3	11
13.00	2	8
16.00	2	6
20.00	1	4
25.00	1	3
32.00	0	2
40.00	0	2
50.00	0	2
63.00	0	1
79.00	0	1
100.00	0	1

Table VI-M-3.— Particulate matter concentrations at various distances downwind for typical cases No. 3 and No. 4

Distance downwind X(km)	Concentration (X)		
	Backing fire	Heading fire	
		CL phase	NCL phase
	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$
0.10	454	5,179	10,132
.13	370	4,196	8,208
.16	303	3,401	6,649
.20	247	2,757	5,386
.25	204	2,237	4,363
.32	169	1,818	3,535
.40	140	1,480	2,864
.50	117	1,208	2,319
.63	98	987	1,873
.79	82	801	1,497
1.00	69	638	1,169
1.30	61	495	883
1.60	51	397	646
2.00	40	329	459
2.50	30	266	319
3.20	22	206	218
4.00	15	153	147
5.00	10	109	98
6.30	7	76	66
7.90	5	52	44
10.00	3	35	29
13.00	2	24	19
16.00	2	16	13
20.00	1	11	8
25.00	1	7	6
32.00	0	6	4
40.00	0	5	4
50.00	0	4	3
63.00	0	3	2
79.00	0	3	2
100.00	0	2	2

Table VI-M-4. — Particulate matter concentrations at various distances downwind for typical cases No. 5 and No. 6

Distance downwind X(km)	Concentration (X)	
	Backing fire	Heading fire in 2-year-old roughs
	$\mu g/m^3$	$\mu g/m^3$
0.10	901	3,302
.13	730	2,675
.16	591	2,167
.20	479	1,756
.25	388	1,422
.32	314	1,152
.40	256	933
.50	206	756
.63	167	612
.79	135	496
1.00	110	402
1.30	90	325
1.60	72	261
2.00	57	206
2.50	45	157
3.20	37	116
4.00	31	83
5.00	25	59
6.30	19	43
7.90	14	32
10.00	10	25
13.00	7	20
16.00	5	15
20.00	3	10
25.00	2	8
32.00	2	7
40.00	1	6
50.00	1	5
63.00	1	4
79.00	1	3
100.00	1	3

Table VI-M-5. — Particulate matter concentrations at various distances downwind for typical cases No. 7 and No. 8

Distance downwind X(km)	Concentration (χ)			
	In winter		In summer	
	CL phase	NCL phase	CL phase	NCL phase
	μg/m3	μg/m3	μg/m3	μg/m3
0.10	30,801	48,633	11,527	18,201
.13	24,952	39,397	9,301	14,687
.16	20,213	31,915	7,505	11,850
.20	16,375	25,855	6,056	9,561
.25	13,265	20,944	4,829	7,625
.32	10,746	16,967	3,851	6,080
.40	8,705	13,745	3,070	4,847
.50	7,052	11,135	2,380	3,758
.63	5,712	9,018	1,827	2,885
.79	4,615	7,287	1,373	2,169
1.00	3,692	5,827	1,002	1,581
1.30	2,887	4,559	708	1,115
1.60	2,188	3,455	487	765
2.00	1,604	2,532	334	512
2.50	1,142	1,803	222	338
3.20	794	1,254	155	220
4.00	543	858	119	142
5.00	367	580	92	91
6.30	248	389	69	58
7.90	173	259	49	38
10.00	127	173	34	24
13.00	98	115	24	17
16.00	76	76	21	14
20.00	57	50	18	11
25.00	42	33	15	9
32.00	36	27	12	8
40.00	32	22	10	6
50.00	28	18	8	5
63.00	23	15	7	4
79.00	19	12	6	4
100.00	16	10	5	3

Table VI-M-6. — Fired-line length correction factors

For typical cases with fired-line length of 400 m when Stability Class C and your fired-line length (meters) is:				For typical cases with fired-line length of 500 m when Stability Class C and your fired-line length (meters) is:			
Distance downwind X (km)	**800**	**1600**	**3200**	**Distance downwind X(km)**	**800**	**1600**	**3200**
0.10	1.0	1.0	1.0	0.10	1.0	1.0	1.0
.13	1.0	1.0	1.0	.13	1.0	1.0	1.0
.16	1.0	1.0	1.0	.16	1.0	1.0	1.0
.20	1.0	1.0	1.0	.20	1.0	1.0	1.0
.25	1.0	1.0	1.0	.25	1.0	1.0	1.0
.32	1.0	1.0	1.0	.32	1.0	1.0	1.0
.40	1.0	1.0	1.0	.40	1.0	1.0	1.0
.50	1.0	1.0	1.0	.50	1.0	1.0	1.0
.63	1.0	1.0	1.0	.63	1.0	1.0	1.0
.79	1.0	1.0	1.0	.79	1.0	1.0	1.0
1.0	1.1	1.1	1.1	1.0	1.0	1.0	1.0
1.3	1.1	1.1	1.1	1.3	1.1	1.1	1.1
1.6	1.2	1.3	1.3	1.6	1.1	1.1	1.1
2.0	1.4	1.4	1.4	2.0	1.2	1.2	1.2
2.5	1.5	1.7	1.7	2.5	1.3	1.4	1.4
3.2	1.6	2.0	2.0	3.2	1.4	1.6	1.6
4.0	1.7	2.3	2.4	4.0	1.4	1.9	2.0
5.0	1.8	2.7	2.9	5.0	1.5	2.2	2.3
6.3	1.9	3.0	3.5	6.3	1.5	2.4	2.8
7.9	1.9	3.3	4.2	7.9	1.5	2.6	3.4
10.0	1.9	3.5	4.9	10.0	1.6	2.8	4.0
13.0	2.0	3.6	5.6	13.0	1.6	2.9	4.5
16.0	2.0	3.8	6.3	16.0	1.6	3.0	5.0
20.0	2.0	3.8	6.7	20.0	1.6	3.1	5.4
25.0	2.0	3.9	7.1	25.0	1.6	3.1	5.7
32.0	2.0	3.9	7.4	32.0	1.6	3.1	5.9
40.0	2.0	3.9	7.6	40.0	1.6	3.2	6.1
50.0	2.0	4.0	7.7	50.0	1.6	3.2	6.2
63.0	2.0	4.0	7.8	63.0	1.6	3.2	6.2
79.0	2.0	4.0	7.9	79.0	1.6	3.2	6.3
100.0	2.0	4.0	7.9	100.0	1.6	3.2	6.3

continued

Table VI-M-6. — Fired-line length correction factors (Continued)

For typical cases with fired-line length of 800 m when Stability Class C and your fired-line length (meters) is:		
Distance downwind X(km)	1600	3200
0.10	1.0	1.0
.13	1.0	1.0
.16	1.0	1.0
.20	1.0	1.0
.25	1.0	1.0
.32	1.0	1.0
.40	1.0	1.0
.50	1.0	1.0
.63	1.0	1.0
.79	1.0	1.0
1.0	1.0	1.0
1.3	1.0	1.0
1.6	1.0	1.0
2.0	1.0	1.0
2.5	1.1	1.1
3.2	1.2	1.2
4.0	1.3	1.4
5.0	1.5	1.6
6.3	1.6	1.9
7.9	1.7	2.2
10.0	1.8	2.5
13.0	1.9	2.9
16.0	1.9	3.2
20.0	1.9	3.4
25.0	2.0	3.6
32.0	2.0	3.7
40.0	2.0	3.8
50.0	2.0	3.9
63.0	2.0	3.9
79.0	2.0	3.9
100.0	2.0	4.0

For typical cases with fired-line length of 500 m when Stability Class B and your fired-line length (meters) is:			
Distance downwind X(km)	800	1600	3200
0.10	1.0	1.0	1.0
.13	1.0	1.0	1.0
.16	1.0	1.0	1.0
.20	1.0	1.0	1.0
.25	1.0	1.0	1.0
.32	1.0	1.0	1.0
.40	1.0	1.0	1.0
.50	1.0	1.0	1.0
.63	1.0	1.0	1.0
.79	1.0	1.0	1.0
1.0	1.1	1.1	1.1
1.3	1.2	1.2	1.2
1.6	1.3	1.4	1.4
2.0	1.4	1.6	1.6
2.5	1.4	1.9	1.9
3.2	1.5	2.1	2.2
4.0	1.5	2.4	2.7
5.0	1.5	2.6	3.3
6.3	1.6	2.8	3.8
7.9	1.6	2.9	4.4
10.0	1.6	3.0	4.9
13.0	1.6	3.1	5.3
16.0	1.6	3.1	5.6
20.0	1.6	3.1	5.9
25.0	1.6	3.2	6.0
32.0	1.6	3.2	6.1
40.0	1.6	3.2	6.2
50.0	1.6	3.2	6.3
63.0	1.6	3.2	6.3
79.0	1.6	3.2	6.3
100.0	1.6	3.2	6.4

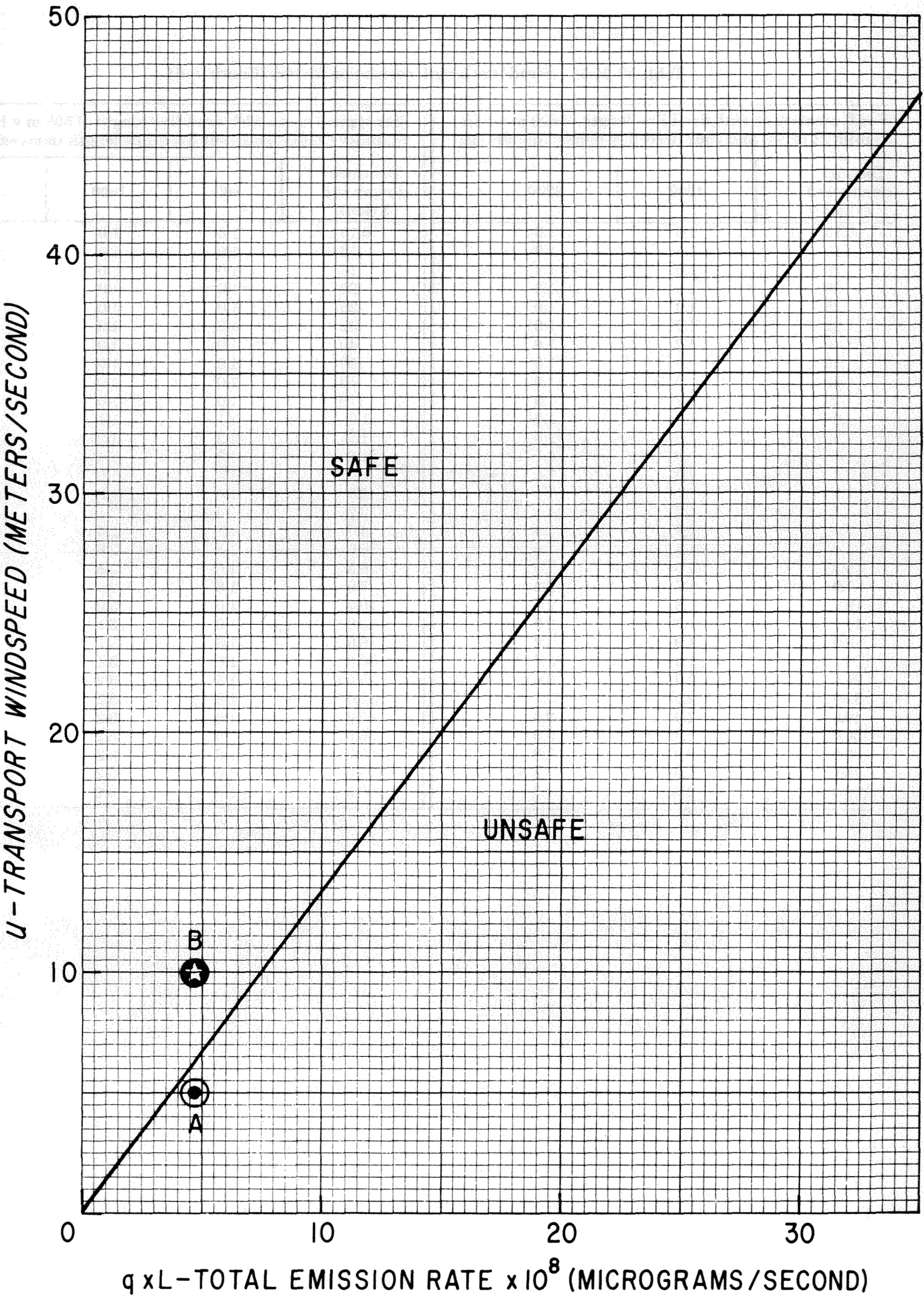


Figure VI-M-1. — Plot of total emission rate (qL) versus transport windspeed (u); ($\frac{qL}{u}$ = 7.5×10^8 $\mu g/m^2$-sec). To help determine if a fire might deliver 150 micrograms of particulate matter per cubic meter of air to a location 60 or more miles downwind, locate the intersection of your total emission rate (emission rate (ER) x fired-line length (L) with your transport windspeed. For example, a fire with an ER of 1,200,000 μg/m-sec and a 400 m line has a total ER of 480,000,000 μg/sec (i.e., 4.8×10^8 μg/sec). Such a fire is unsafe if the transport windspeed is 5 m/sec, but safe if it is 10 m/sec. (See example plotted as A and B, respectively.)

LITERATURE CITED

Blackmarr, W. H.

1971. Equilibrium moisture content of common fine fuels found in southeastern forests. USDA For. Serv. Res. Pap. SE-74, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

Deeming, John E., James W. Lancaster, Michael A. Fosberg, and others

1972. National fire-danger rating system. USDA For. Serv. Res. Pap. RM-84, 165 p. Rocky Mt. For. & Range Exp. Stn., Fort Collins, Colo.

Hough, Walter A., and Frank A. Albini

In press. Predicting fire behavior in palmetto-gallberry fuel complexes. USDA For. Serv. Res. Pap. Southeast. For. Exp. Stn., Asheville, N.C.

McNab, W. Henry, and M. Boyd Edwards, Jr.

1976. Estimating forest fuel buildup. For. Farmer 35(5):6-7.

Metz, Louis J.

1958. Moisture held in pine litter. J. For. 56(1):36.

Rothermel, Richard C.

1972. A mathematical model for predicting fire spread in wildland fuels. USDA For. Serv. Res. Pap. INT-115, 40 p. Intermountain For. & Range Exp. Stn., Ogden, Utah.

GLOSSARY

Advancing-front combustion stage. — The period of combustion when a fire is spreading, usually accompanied by flaming combustion that releases heat that sustains the convection column.

Aerosol. — See **Particulate matter.**

Age of rough. — Time in years since the forest fuel was last reduced.

Ambient air. — Literally, the air moving around us; the air of the surrounding environment.

Available fuel. — The portion of the total combustible woody material that fire will consume under given conditions.

Backing fire. — A fire spreading against the wind. Flames tilt away from direction of spread.

Basal area. — The area of the cross section of a tree stem near its base, generally at breast height and inclusive of bark.

Bound water. — Bound moisture. Moisture that is intimately associated with the finer wood elements of the cell wall by molecular sorption.

Breast height. — On standing trees, a standard height (4-1/2 feet) from ground level for recording diameter, girth, or basal area.

Broadcast burn. — The burning of forest residue scattered over an area.

Char. — Charcoal. The residue from the destructive distillation of wood or animal matter with exclusion of air; contains carbon and inorganic matter.

Clearcutting. — Strictly, the *removal* of the entire standing crop.

Climax. — The culminating stage in plant succession for a given environment, the vegetation being conceived or having reached a highly stable condition.

Coagulation. — A separation or precipitation from a dispersed state of suspended particles resulting from their growth.

Combustion. — The burning or rapid oxidation of the pyrolysate vapors escaping from the surface of the fuel.

Condensation. — (1) The linking together of two or more molecules, resulting in the formation of long-chain compounds. (2) The process of forming a liquid from its vapor.

Convection column. — That portion of a smoke plume sharply defined by the buoyant forces of heated air and effluents.

Convective-lift fire phase. — The phase of a fire when most of the emissions are entrained into a definite convection column.

Cord. — A unit of gross volume measurement for stacked round or cleft wood; i.e., based on external dimensions. A standard cord contains 128 stacked cubic feet and generally implies a stack of 4 x 4 feet vertical cross section x 8 feet long, with a small percent extra in height to allow for settlement.

Crop tree. — Any tree forming, or selected to form, a component of the final crop.

Decomposition. — The more or less permanent breaking down of a molecule into simpler molecules or atoms.

Denitrification. — Reducing nitrates to nitrites, nitrous oxide, or nitrogen under anaerobic conditions.

d.b.h. — Diameter at breast height (4-1/2 feet above ground level).

Diffusion. — In meteorology, the exchange of fluid parcels (and hence the transport of conservative properties) between regions in space, in the apparently random motions of a scale too small to be treated by the equations of motion.

Dispersion. — In air pollution terminology, loosely applied to the removal (by whatever means) of pollutants from the atmosphere over a given area; or the distribution of a given quantity of pollutant throughout an increasing volume of atmosphere.

Eddy. — Any circulation drawing its energy from a flow of much larger scale, and brought about by pressure irregularities as in the lee of a solid obstacle.

Effluent. — The mixture of substances, gases and liquids, and suspended matter, discharged into the atmosphere (or ground, river, ocean) as the result of a given process.

Emission. — Pollutants released to the atmosphere from any combustion process. Sometimes used synonymously with effluent, but it is more applicable to atmospheric discharges.

Emission factor. — The quantity of pollutant released to the atmosphere per unit weight of dry fuel consumed during combustion (pounds per ton).

Emission rate. — The quantity of pollutant released to the atmosphere per unit of time per unit length of fire front.

Fermentation layer. — The layer consisting of partly decomposed organic matter. The structure of the plant debris is generally well enough preserved to permit identification of its source.

Fine fuel. — Flash fuels. Fuels; e.g., grass, ferns, leaves, draped (i.e., intercepted when falling) needles, tree moss, and some kinds of light slash, that ignite readily and are consumed rapidly by fire when dry.

Fire behavior. — The manner in which fuel ignites, flame develops, and fire spreads and exhibits other phenomena.

Firing technique. — A method of igniting a wild land area to consume the fuel in a prescribed pattern; e.g., heading or backing fire, spot fire, strip-head fire, and ring fire.

Flaming combustion. — Luminous oxidation of the gases evolved from the decomposition of the fuel.

Flaming phase. — That phase of a fire where the fuel is ignited and consumed by flaming combustion.

Fossil fuels. — Coal, oil, and natural gas; so called because they are the remains of ancient plant and animal life.

Free water. — Free moisture. In wood, moisture contained in the cell cavities and intercellular spaces and held by capillary forces only.

Fuel loading. — The amount of fuel present expressed quantitatively in terms of weight of fuel per unit area. This may be available fuel or total fuel and is usually dry weight.

Fuel type. — An identifiable association of fuel elements of distinctive species, form, size, arrangement, or other characteristics, that will cause a predictable rate of fire spread or difficulty of control, under specified weather conditions.

Glowing phase. — That phase of a fire where the char left from the flaming phase is consumed by solid oxidation.

Heading fire. — A fire spreading with the wind. Flames tilt in the direction of spread.

Heat release rate to the atmosphere. — The amount of heat released to the atmosphere from the advancing-front combustion stage of a fire per unit of time.

Heat yield. — To a very close approximation, the quantity of heat per pound of fuel burned that passes through a cross section of the convection column above a fire that is burning in a neutrally stable atmosphere.

Herbaceous. — Soft and green, containing little woody tissue.

Hydrocarbons. — A general term for organic compounds that contain only carbon and hydrogen in the molecule. They are divided into saturated and unsaturated hydrocarbons, aliphatic (paraffin or fatty), and aromatic (benzene) hydrocarbons.

Humus. — (1) A general term for the more or less decomposed (plant and animal) residues in the soil; litter, therefore, being excluded. (2) More specifically, the more or less stable fraction from the decomposed soil organic material, generally amorphous, colloidal, and dark colored.

Inversion. — Temperature inversion. A layer in which temperature increases with altitude.

Litter. — The uppermost layer, the L-layer, or organic debris on a forest floor; i.e., essentially the freshly fallen or only slightly decomposed vegetable material—mainly foliate (leaf litter)—but also bark fragments, twigs, flowers, fruits, etc.

Micron. — One millionth of a meter, a micrometer.

Mixing. — A random exchange of fluid parcels on any scale from the molecular to the largest eddy.

Mixing height. — The height to which relatively vigorous mixing occurs (meters).

Model. — A mathematical or physical system, obeying certain specified conditions, whose behavior is used to understand a physical, biological, or social system to which it is analogous in some way.

Moisture content. — The amount of water present in a material; e.g., wood or soil, generally expressed as a percent of the material's ovendry weight.

National Fire-Danger Rating System. — The method currently used by the USDA Forest Service and other Federal, State, and county agencies to uniformly describe the cumulative effects of weather on wildfire behavior.

Naval stores. — A term of historical pedigree, still applied to the products of the United States resin industry, nowadays particularly to turpentine and resin, but also to pine tars and pitch.

No-convective-lift fire phase. — The phase of a fire when most emissions are not entrained into a definite convective column.

Nucleate. — To form into or around a nucleus, as in the formation of particulate matter.

Organic soil. — Any soil or soil horizon consisting chiefly of, or containing at least 30 percent of organic matter; examples are peat soil and muck soil.

Ovendry. — Of wood dried to constant weight in a ventilated oven at a temperature above the boiling point of water, generally 103 $\pm$ °C.

Overstory. — That portion of the trees, in a forest of more than one story, forming the upper or uppermost canopy layer; e.g., frequent emergents in multi-storied tropical forests or, in a two-storied forest, seed bearers over regeneration and standards over coppice.

Particulate matter. — Any liquid or solid particles suspended in or falling through the atmosphere.

Total suspended particulate matter (TSP) is that portion of the total particulate matter that, because of its size (below 5 to 10 microns in diameter), is transported long distances in the atmosphere and has the greatest potential for environmental impact. Respirable suspended particulate matter (RSP) is that portion of the total particulate matter that, because of its size (below 2 to 3 microns in diameter), has an especially long residence time in the atmosphere and penetrates deeply into the lungs. Aerosol is used interchangeably for the smaller airborne particulate matter by many authorities. However, aerosols are more precisely defined as particles in a gaseous medium.

Particulate mass concentration. — The amount of particulate matter per unit volume of air ($\mu g/m^3$).

Perturbation. — Any departure introduced into an assumed steady state of a system.

Photochemical process. — The chemical changes brought about by the radiant energy of the sun acting upon various polluting substances. The products are known as photochemical smog.

Photosynthesis. — The building up of organic compounds, particularly carbohydrates, in green cells, from CO_2 in the presence of H_2O and light, the energy of the latter being transformed by chlorophyll and enzymes.

Physiological. — Relating to the functions of plant or animal as a living organism.

Plume. — The segment of the atmosphere occupied by any of the emissions from a single source. A convection column, if one exists, forms a specific part of the plume.

Point source. — See **Source.**

Pollutant. — With respect to the atmosphere, any substance within it that is foreign to the *natural* atmosphere or that exceeds its *natural* concentrations in the atmosphere. The universal connotation is that a pollutant is potentially deleterious.

Polymer. — A complex molecule formed from the combination of several molecules and having the same empirical formula as the simple ones.

Pre-ignition phase. — That phase of a fire when the fuel is heated to ignition temperature.

Prescribed burning. — Controlled application of fire to wild land fuels in either their natural or modified state, under such conditions of weather, fuel moisture, soil moisture, etc., as allows the fire to be confined to a predetermined area and at the same time to produce the intensity of heat and rate of spread required to further certain planned objectives of silviculture, wildlife habitat management, grazing, fire hazard reduction, etc.

Pyrolysis. — The thermal or chemical decomposition of fuel at an elevated temperature.

Rate of spread. — The amount that a fire extends its horizontal dimensions within a unit of time. This can be expressed as forward rate of spread of the advancing fire front, area rate of spread, or perimeter rate of spread.

Residual combustion stage. — The smoldering zone behind the zone of an advancing fire front.

Respirable suspended particulate matter (RSP). — See Particulate matter.

Rough. — An accumulation of living or dead material that is susceptible to burning.

Smoke management. — Conducting a prescribed fire under fuel moisture and meteorological conditions, and with firing techniques that keep the smoke's impact on the environment within acceptable limits.

Smoldering phase. — The combined processes of dehydration, pyrolysis, solid oxidation, and scattered flaming often occurring after the flaming phase of a fire. Often characterized by emissions of large amounts of smoke.

Soluble. — That can be dissolved; capable of passing into solution, as sugar is soluble in water.

Sorption. — The uptake and retention of one substance (the sorbate) at the surface (adsorption) or in the interior (absorption) of another (the sorbent).

Source. — A point, line, area, or volume at which mass or energy is added to a system, either instantaneously or continuously. Conversely, at a *sink,* mass or energy is removed. Examples of sources in the context of air pollution are as follows: a smoke stack is a *point source;* a freeway or aircraft trajectory is a *line source.*

Surface fuel. — The loose surface litter on the forest floor, normally consisting of fallen leaves or needles, twigs, bark, cones, and small branches that have not yet decayed sufficiently to lose their identity. Also grasses, shrubs less than 4 feet in height, heavier branchwood, down logs, stumps, seedlings, and forbs interspersed with or partially replacing the litter.

Synergism. — The cooperative action of separate substances which, together, have greater total effect than the sum of their individual effects.

Target. — Any place at which adverse effects of smoke concentrations may be experienced.

Temperate zone. — Either of two zones of the Earth between the Tropics and the Polar circles.

Thermal energy. — Heat energy.

Total fuel. — The total combustible woody material.

Total suspended particulate matter (TSP). — See **Particulate matter.**

Toxic. — Relating to a harmful effect by a poisonous substance on the human body by physical contact, ingestion, or inhalation.

Transport windspeed. — A measure of the average rate of the horizontal transport of air within the mixing layer (meters per second).

Turbulence. — A complex spectrum of fluctuating, disordered motion superimposed on the mean flow of a liquid or gas.

Understory. — Any plants growing under the canopy formed by others—more particularly—herbaceous and shrub vegetation under a brushwood or tree canopy.

METRIC CONVERSION AND PREFIX TABLE

Metric Conversion

From	Symbol	To	Symbol	Multiply by
		Length		
Inches	in	Centimeters	cm	2.54
Centimeters	cm	Inches	in	0.3937
Feet	ft	Meters	m	0.3048
Meters	m	Feet	ft	3.281
Miles	mile	Kilometers	km	1.609
Kilometers	km	Miles	mile	0.6214
		Area		
Acres	acre	Square meters	m^2	4047
Square meters	m^2	Acres	acre	0.00025
Acres	acre	Hectares	ha	0.4047
Hectares	ha	Acres	acre	2.471
		Volume		
Cubic inches	in^3	Cubic centimeters	cm^3	16.39
Cubic centimeters	cm^3	Cubic inches	in^3	0.061
Cubic feet	ft^3	Cubic meters	m^3	0.0283
Cubic meters	m^3	Cubic feet	ft^3	35.31
		Mass		
Pounds	lbs	Grams	g	453.6
Grams	g	Pounds	lbs	0.0022
Pounds	lbs	Kilograms	kg	0.4536
Kilograms	kg	Pounds	lbs	2.205
Short tons	sh. ton	Metric tons	m. ton	0.9072
Metric tons	m. ton	Short tons	sh. ton	1.102
		Speed		
Feet/minute	ft/min	Meters/minute	m/min	0.3048
Meters/minute	m/min	Feet/minute	ft/min	3.281
Miles/hour	mph	Kilometers/hour	km/hr	1.609
Kilometers/hour	km/hr	Miles/hour	mph	0.6214
		Temperature		
Fahrenheit	°F	Celsius	°C	5/9 after subtracting 32
Celsius	°C	Fahrenheit	°F	9/5 then add 32
		Energy		
British thermal units	Btu	Calories	cal	252.0
Calories	cal	British thermal units	Btu	0.004

Multiple	Prefix Prefix	Prefix Symbol
$1,000,000,000 = 10^9$	giga	G
$1,000,000 = 10^6$	mega	M
$1,000 = 10^3$	kilo	k
$100 = 10^2$	hecto	h
$10 = 10^1$	deka	da
$1 = 10^0$		
$0.1 = 10^{-1}$	deci	d
$0.01 = 10^{-2}$	centi	c
$0.001 = 10^{-3}$	milli	m
$0.000\,001 = 10^{-6}$	micro	μ
$0.000\,000\,001 = 10^{-9}$	nano	n

SPECIAL ACKNOWLEDGMENTS

While the authors accept full responsibility for their final products, we all gratefully acknowledge the contributions of the following individuals in reviewing portions of this Guidebook.

Entire Guidebook

A. P. Brackebusch, National Fire Specialist
State and Private Forestry
USDA Forest Service

Craig C. Chandler, Director
Forest Fire & Atmospheric Sciences
Research
USDA Forest Service

Sharon R. Miller, Chairman
Smoke Management Research Coordinating Committee and
Director, Forest Management & Research
The Chesapeake Corporation

Perspectives

Edward W. Burt
Source Receptor Analyses Branch
Region IV
U.S. Environmental Protection Agency

Dr. E. V. Komarek, Director
Tall Timbers Research Station

Dr. Paul Urone, Professor
Environmental Engineering Sciences
University of Florida

Walt Myers, Editor
Forest Farmer Magazine

Chapter I: Smoke Management - What Is It?

W. D. Baughman, Assistant Woodlands Manager
Westvaco Corporation

Dr. Charles W. Philpot, Assistant Station Director
Pacific Southwest Forest & Range Experiment Station
USDA Forest Service

Ronald J. Strauss, Fire Management Staff Officer
National Forests in Mississippi

Chapter II: Contents and Effects of Forest Fire Smoke

Dr. Alfred H. Ellison, Deputy Director
Environmental Sciences Research Laboratory
U.S. Environmental Protection Agency

Lee Monteith, Senior Chemist
Department of Environmental Health
University of Washington

Dr. Charles W. Philpot, Assistant Station Director
Pacific Southwest Forest & Range Experiment Station
USDA Forest Service

Dr. Paul Urone, Professor
Environmental Engineering Sciences
University of Florida

Chapter III: Air Quality Administration

William M. Burch, Chief
Air Strategy Development Section
Region IV
U.S. Environmental Protection Agency

James N. Hale, Environmental Administrator
Air Quality Management
Florida Dep. of Environmental Regulations

Harry F. Wieshahn, Engineer
Division of Air Pollution Control
Tennessee Dep. of Public Health

Chapter IV: Fuels, Fire Behavior, and Emissions

Dr. Frank A. Albini, Research Mechanical Engineer
Northern Forest Fire Laboratory
Intermountain Forest & Range Experiment Station
USDA Forest Service

John E. Deeming, Project Leader
Northern Forest Fire Laboratory
Intermountain Forest & Range Experiment Station
USDA Forest Service

Dr. David Sandberg, Assistant Professor
School of Forestry
Colorado State University

Chapter V: Smoke Transport and Dispersion

Dr. Gary A. Briggs, Research Meteorologist
Atmospheric Turbulence & Diffusion Laboratory
Environmental Research Laboratories
National Oceanic & Atmospheric Administration

Edward W. Burt
Source Receptor Analyses Branch
Region IV
U.S. Environmental Protection Agency

Douglas G. Fox, Project Leader
Rocky Mountain Forest & Range Experiment Station
USDA Forest Service

Lewis H. Nagler, Regional Meteorologist
Region IV
U.S. Environmental Protection Agency

Charles F. Roberts, Senior Research Meteorologist
Forest Fire & Atmospheric Sciences Research
USDA Forest Service

Dr. D. Bruce Turner, Chief
Environmental Applications Branch
National Environmental Research Center
U.S. Environmental Protection Agency

Dansy T. Williams, Research Meteorologist
Southeastern Forest Experiment Station
Southern Forest Fire Laboratory
USDA Forest Service

Chapter VI: How to Manage Smoke

Brian F. Anholt, Operations Research Analyst
Pacific Northwest Forest & Range Experiment Station
USDA Forest Service

Marty Fox, Chief Forester
Federal Paperboard Company

Wally Lancaster, Fire Specialist
Boise Interagency Fire Center
USDA Forest Service

Charles Maynard, Fire Control Research Coordinator
Division of Forestry
Florida Department of Agriculture & Consumer Services

Lambert H. Romero, Chief
Forest Protection
Louisiana Forestry Commission

In addition to the above named reviewers, the authors wish to thank all other members of the staff at the Southern Forest Fire Laboratory for their helpful advice and other assistance while the Guidebook has been in progress.

ERRATA SHEET

SOUTHERN FORESTRY SMOKE MANAGEMENT GUIDEBOOK

To save space and avoid duplication, tables necessary for making predictions are printed only on the colored sheets. The descriptions (on white sheets) of the use of these tables contain page references that are incorrect. The correct paging for work tables is:

Table number	Page
VI-F-1	110
VI-F-2	111
VI-F-3	112
VI-F-4	113
VI-F-5	114
VI-F-6	115
VI-F-7	116
VI-F-8	117
VI-F-9	118
VI-F-10	119
VI-F-11	120
VI-F-12	121
VI-F-13	122
VI-M-1	123
VI-M-2	124
VI-M-3	125
VI-M-4	126
VI-M-5	127
VI-M-6	128

Southern Forest Fire Laboratory Staff

1976. Southern forestry smoke management guidebook. USDA For. Serv. Gen. Tech. Rep. SE-10, 140 p. Southeast. For. Exp. Stn., Asheville, N.C.

A system for predicting and modifying smoke concentrations from prescription fires is introduced. While limited to particulate matter and the more typical southern fuels, the system is for both simple and complex applications. Forestry smoke constituents, variables affecting smoke production and dispersion, and new methods for estimating available fuel are presented.

Keywords: Air quality, pollution, prescribed burning, smoke management, particulate matter, smoke concentrations, emission factors, components of forestry smoke, fuel loading.

Southern Forest Fire Laboratory Staff

1976. Southern forestry smoke management guidebook. USDA For. Serv. Gen. Tech. Rep. SE-10, 140 p. Southeast. For. Exp. Stn., Asheville, N.C.

A system for predicting and modifying smoke concentrations from prescription fires is introduced. While limited to particulate matter and the more typical southern fuels, the system is for both simple and complex applications. Forestry smoke constituents, variables affecting smoke production and dispersion, and new methods for estimating available fuel are presented.

Keywords: Air quality, pollution, prescribed burning, smoke management, particulate matter, smoke concentrations, emission factors, components of forestry smoke, fuel loading.

GROWING
FROM '76

U.S. FORESTRY
CENTENNIAL

NATIONAL FOREST SYSTEM
COOPERATIVE FORESTRY
FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE
FORESTRY RESEARCH

Wildfire Smoke

A Guide for Public Health Officials

Acknowledgements

This document was written by Harriet Ammann, Washington Department of Health; Robert Blaisdell and Michael Lipsett, California Office of Environmental Health Hazard Assessment, Susan Lyon Stone, U.S. Environmental Protection Agency; and Shannon Therriault, Missoula County Health Department, with input from individuals in several other state and federal agencies, in particular Jed Waldman of the California Department of Health Services, Peggy Jenkins of the California Air Resources Board, and editorial support from Kate Lynch, Washington State Department of Health. It was developed in part as a result of a workshop held at the University of Washington in June 2001, under the auspices of the U.S. Environmental Protection Agency, Region X, and the Department of Environmental Health, School of Public Health and Community Medicine of the University of Washington. The viewpoints and policies expressed in this document do not necessarily represent those of the various agencies and organizations listed. Mention of any specific product name is neither an endorsement nor a recommendation for use.

Introduction

Smoke rolls into town, blanketing the city, turning on streetlights, creating an eerie and choking fog. Switchboards light up as people look for answers. Citizens want to know what they should do to protect themselves. Schools officials want to know if outdoor events should be cancelled. The news media want to know how dangerous the smoke really is.

Smoke events often catch us off-guard. This guide is intended to provide local public health officials with the information they need when wildfire smoke is present so they can adequately communicate health risks and precautions to the public. It is the product of a collaborative effort by scientists, air quality specialists and public health professionals from Federal, state and local agencies.

Composition of smoke

Smoke is composed primarily of carbon dioxide, water vapor, carbon monoxide, particulate matter, hydrocarbons and other organic chemicals, nitrogen oxides, trace minerals and several thousand other compounds. The actual composition of smoke depends on the fuel type, the temperature of the fire, and the wind conditions. Different types of wood and vegetation are composed of varying amounts of cellulose, lignin, tannins and other polyphenolics, oils, fats, resins, waxes and starches, which produce different compounds when burned.

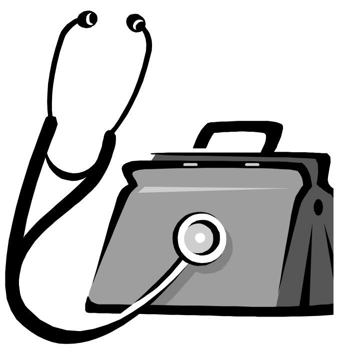
Particulate matter is the principal pollutant of concern from wildfire smoke for the relatively short-term exposures (hours to weeks) typically experienced by the public. Particulate matter is a generic term for particles suspended in the air, typically as a mixture of both solid particles and liquid droplets. Particles from smoke tend to be very small - less than one micrometer in diameter. For purposes of comparison, a human hair is about 60 micrometers in diameter.   Particulate matter in wood smoke has a size range near the wavelength of visible light (0.4 – 0.7 micrometers). Thus, smoke particles efficiently scatter light and reduce visibility. Moreover, such small particles can be inhaled into the deepest recesses of the lung and are thought to represent a greater health concern than larger particles.

Another pollutant of concern during smoke events is carbon monoxide. Carbon monoxide is a colorless, odorless gas, produced by incomplete combustion of wood or other organic materials. Carbon monoxide levels are highest during the smoldering stages of a fire.

Other air pollutants, such as acrolein, benzene, and formaldehyde, are present in smoke, but in much lower concentrations than particulate matter and carbon monoxide.

Health effects of smoke

The effects of smoke range from eye and respiratory tract irritation to more serious disorders, including reduced lung function, bronchitis, exacerbation of asthma, and premature death. Studies have found that fine particles are linked (alone or with other pollutants) with increased mortality and aggravation of pre-existing respiratory and cardiovascular disease. In addition, particles are respiratory irritants, and exposures to high concentrations of particulate matter can cause persistent cough, phlegm, wheezing and difficulty breathing. Particles can also affect healthy people, causing respiratory symptoms, transient reductions in lung function, and pulmonary inflammation. Particulate matter can also affect the body's immune system and make it more difficult to remove inhaled foreign materials from the lung, such as pollen and bacteria. The principal public health threat from short-term exposures to smoke is considered to come from exposure to particulate matter.



Carbon monoxide (CO) enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. The CO concentrations typical of population exposures related to wildfire smoke do not pose a significant hazard, except to some sensitive individuals and to firefighters very close to the fire line. Individuals who may experience health effects from lower levels of CO are those who have cardiovascular disease: they may experience chest pain and cardiac arrhythmias. At higher levels, as might be observed in a major structural fire, carbon monoxide exposure can cause headaches, dizziness, visual impairment, reduced work capacity, and reduced manual dexterity, even in otherwise healthy individuals. At even higher concentrations (seldom associated solely with a wildfire), carbon monoxide can be deadly.

Wildfire smoke also contains significant quantities of respiratory irritants. Formaldehyde and acrolein are two of the principal irritant chemicals that add to the cumulative irritant properties of smoke, even though the concentrations of these chemicals individually may be below levels of public health concern.

One concern that may be raised by members of the general public is whether they run an increased risk of cancer or other long-term health impacts of exposure to wildfire smoke. People exposed to toxic air pollutants at sufficient concentrations and durations may have slightly increased risks of cancer or of experiencing other chronic health problems. However, in general, the long-term risk from short-term smoke exposure is quite low. Epidemiological studies have shown that urban firefighters exposed to smoke over an entire working lifetime have about a three-fold increased risk of developing lung cancer (Hansen 1990). This provides some perspective on the potential risks. The major carcinogenic components of smoke are polycyclic aromatic hydrocarbons (PAHs). Although the carcinogens benzene and formaldehyde are also present in smoke, they are thought to present a lesser risk.

Not everyone who is exposed to thick smoke will have health problems. The level and duration of exposure, age, individual susceptibility, including the presence or absence of pre-existing lung or heart disease, and other factors play significant roles in determining whether or not someone will experience smoke-related health problems.

Sensitive populations

Most healthy adults and children will recover quickly from smoke exposures and will not suffer long-term consequences. However, certain sensitive populations may experience more severe short-term and chronic symptoms from smoke exposure. Much of the information about how particulate matter affects these groups has come from studies involving airborne particles in cities, though a few studies examining the effects of exposure to smoke suggest that the health effects of wildfire smoke are likely to be similar. More research is needed to determine whether particles from wildfires affect susceptible subpopulations differently.

Individuals with asthma and other respiratory diseases: Levels of pollutants that may not affect healthy people may cause breathing difficulties for people with asthma or other chronic lung diseases. Asthma, derived from the Greek word for panting, is a condition characterized by chronic inflammation of the airways, with intermittent bronchoconstriction and airflow obstruction, causing shortness of breath, wheezing, chest tightness, coughing, sometimes accompanied by excess phlegm production. During an asthma attack, the muscles tighten around the airways and the lining of the airways becomes inflamed and swollen, constricting the free flow of air. Because children's airways are narrower than those of adults, irritation that would create minor problems for an adult may result in significant obstruction in the airways of a young child. However, the highest mortality rates from asthma occur among older adults.

Individuals with chronic obstructive pulmonary disease (COPD), which is generally considered to encompass emphysema and chronic bronchitis, may also experience a worsening of their conditions because of exposure to wildfire smoke. Patients with COPD often have an asthmatic component to their condition, which may result in their experiencing asthma-like symptoms. However, because their pulmonary reserve has typically been seriously compromised, additional bronchoconstriction in individuals with COPD may result in symptoms requiring medical attention. Epidemiological studies have indicated that individuals with COPD run an increased risk of requiring emergency medical care after exposure to particulate matter or forest fire smoke. Exposure to smoke may also depress the lung's ability to fight infection. People with COPD may develop lower respiratory infections after exposure to wildfire smoke, which may require urgent medical care as well. In addition, because COPD is usually the result of many years of smoking, individuals with this condition may also have heart disease, and are potentially at risk from both conditions.

Individuals with airway hyperresponsiveness: A significant fraction of the population may have airway hyperresponsiveness, an exaggerated tendency of the bronchi and bronchioles to constrict in response to respiratory irritants and other stimuli. While airway hyperresponsiveness is considered a hallmark of asthma, this tendency may also be found in many nonasthmatics, as well; for example, during and following a lower respiratory tract infection. In such individuals, smoke exposure may cause bronchospasm and asthma-like symptoms.

Individuals with cardiovascular disease: Diseases of the circulatory system include, among others, high blood pressure, cardiovascular diseases, such as coronary artery disease and congestive heart failure, and cerebrovascular conditions, such as atherosclerosis of the arteries bringing blood to the brain. These chronic conditions can render individuals susceptible to attacks of angina pectoris, heart attacks, sudden death due to a cardiac arrhythmia, acute congestive heart failure, or stroke. Cardiovascular diseases represent the leading cause of death in the United States, responsible for about 30 to 40 percent of all deaths each year. The vast majority of these deaths are in people over the age of 65. Studies have linked urban particulate matter to increased risks of heart attacks, cardiac arrhythmias, and other adverse effects in those with cardiovascular disease. People with chronic lung or heart disease may experience one or more of the following symptoms: shortness of breath, chest tightness, pain in the chest, neck, shoulder or arm, palpitations, or unusual fatigue or lightheadedness. Chemical messengers released into the blood because of particle-related lung inflammation may increase the risk of blood clot formation, angina episodes, heart attacks and strokes.

The elderly. In several studies researchers have estimated that tens of thousands of elderly people die prematurely each year from exposure to particulate air pollution, probably because the elderly are more likely to have pre-existing lung and heart diseases, and therefore are more susceptible to particle-associated effects. The elderly may also be more affected than younger people because important respiratory defense mechanisms may decline with age. Particulate air pollution can compromise the function of alveolar macrophages, cells involved in immune defenses in the lungs, potentially increasing susceptibility to bacterial or viral respiratory infections.

Children. Children, even those without any pre-existing illness or chronic conditions, are considered a sensitive population because their lungs are still developing, making them more susceptible to air pollution than healthy adults. Several factors lead to increased exposure in children compared with adults: they tend to spend more time outside; they engage in more vigorous activity, and they inhale more air (and therefore more particles) per pound of body weight. Studies have shown that particulate pollution is associated with increased respiratory symptoms and decreased lung function in children, including symptoms such as episodes of coughing and difficulty breathing. These can result in school absences and limitations of normal childhood activities.

Pregnant women. While there have not been studies of the effects of exposure to wildfire smoke on pregnancy outcomes, there is substantial evidence of adverse effects of repeated exposures to cigarette smoke, including both active and passive smoking. Wildfire smoke contains many of the same compounds as cigarette smoke. In addition, recent data suggest that exposures to ambient air pollution in cities may result in low birthweight and possibly other, more serious adverse reproductive effects. Therefore, it would be prudent to consider pregnant women as a potentially susceptible population as well.

Smokers. People who smoke, especially those who have smoked for many years, have already compromised their lung function. However, due to adaptation of their lungs to ongoing irritation, smokers are less likely to report symptoms from exposure to irritant chemicals than are nonsmokers. However, they may still be injured by wildfire smoke. Therefore, some smokers may unwittingly put themselves at greater risk of potentially harmful wildfire smoke exposures, believing that they are not being affected.

Recommendations for the public

Pre-season public service announcements

In areas where fires are likely to occur, state and local public health agencies should consider running pre-season public service announcements (PSAs) or news releases to advise the public on how to prepare for the fire season. PSAs should be simple (e.g., the season for wildfires is approaching; there are things you can do now to help protect your health and prepare your home in the event of a wildfire), and should list a contact phone number or website for further information.

News releases should be used to provide more detailed information, including information for the general public and for people with chronic diseases.

General recommendations to the public should include at least the following:

1. Have a several-day supply of nonperishable groceries that do not require cooking, since cooking can add to indoor pollutant levels.
2. If you develop symptoms suggestive of lung or heart problems, consult a health-care provider as soon as possible.
3. Be alert to PSAs.
4. Be aware that outdoor events, such as athletic games or competitions, may be postponed or cancelled if smoke levels become elevated.

Recommendations for people with chronic diseases should include at least the following:

1. Have an adequate supply of medication (more than 5 days)
2. People with asthma should have a written asthma management plan.
3. Contact a health-care provider if your condition worsens when you are exposed to smoke.
4. A news release could also include recommendations for preparing residences to keep smoke levels lower indoors, and on the appropriate use of facemasks. A sample news release developed by the Washington State Department of Health can be found in Appendix B.

Public advisories and protective measures

Table 2 provides a general list of health effects and cautionary statements for use in public advisories. The categories are based on the Environmental Protection Agency's Air Quality Index (AQI), as well as work done in Montana, California and Washington. (For more information on the AQI, see http://www.epa.gov/airnow/aqibroch/). The recommended $PM_{2.5}$ concentrations (1- to 3-hour averages) at which these advisories should be issued are listed in Table 3. If only PM_{10} measurements are available, and conditions are smoky, it should be assumed that the PM_{10} levels are composed primarily of fine particles ($PM_{2.5}$), and the AQI for PM_{10} should be used.

Table 3 provides guidance to public health officials on measures that can be taken to protect public health. These levels are intended for use in extraordinary circumstances to help public health authorities, the media, and the general public make decisions regarding appropriate strategies to mitigate exposure to smoke. It should be recognized that there are no directly relevant epidemiological or controlled human exposure studies that offer guidance in the selection of these levels, in part because studies of short-term effects of particles generally have not been conducted and in part because the toxicity of smoke is likely related to gases in smoke as well as particles.

Table 2. Health Effects and Cautionary Statements

Category (see Table 3)	**Health Effects**	**Cautionary Statements**[1]	**Other Protective Actions**
Good	None expected	None	None
Moderate	Possible aggravation of heart or lung disease	Unusually sensitive individuals should consider limiting prolonged or heavy exertion. - People with heart or lung disease should pay attention to symptoms - If you have symptoms of lung or heart disease, including repeated coughing, shortness of breath or difficulty breathing, wheezing, chest tightness or pain, palpitations, nausea, unusual fatigue or lightheadedness, contact your health care provider.	- If symptomatic, reduce exposure to particles by following advice in box below.
Unhealthy for Sensitive Groups	Increasing likelihood of respiratory or cardiac symptoms in sensitive individuals, aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly.	*Sensitive Groups:* People with heart or lung disease, the elderly, children and pregnant women should limit prolonged or heavy exertion. - Limit time spent outdoors - Avoid physical exertion - People with asthma should follow asthma management plan - If you have symptoms of lung or heart disease that may be related to excess smoke exposure, including repeated coughing, shortness of breath or difficulty breathing, wheezing, chest tightness or pain, heart palpitations, nausea, unusual fatigue or lightheadedness, contact your health care provider.	- Keep doors and windows closed, seal large gaps as much as possible - If cooling is needed, turn air-conditioning to re-circulate mode in home and car, or use ceiling fans or portable fans (but do not use whole house fans that suck outdoor air into the home). - Avoid indoor sources of pollutants, including tobacco smoke, heating with wood stoves and kerosene heaters, frying or broiling foods, vacuuming, and using paints, solvents, and adhesives - Keep at least 5-day supply of medication available. - Have supply of non-perishable groceries that do not require cooking.

[1] Higher advisory levels automatically incorporate all of guidance offered at lower levels.

Table 2. Health Effects and Cautionary Statements (continued)

Category (see Table 3)	**Health Effects**	**Cautionary Statements**[1]	**Other Protective Actions**
Unhealthy	Increased aggravation of heart or lung disease and premature mortality in persons with cardiopulmonary disease and the elderly; increased respiratory effects in general population.	*Sensitive Groups:* should avoid prolonged or heavy exertion - Stay indoors; avoid exertion. *General Population:* should limit prolonged or heavy exertion - Limit time spent outdoors - If you have symptoms of lung or heart disease that may be related to excess smoke exposure, including repeated coughing, shortness of breath or difficulty breathing, wheezing, chest tightness or pain, palpitations, nausea or unusual fatigue or lightheadedness, contact your health care provider.	*Sensitive Groups:* - Stay in a "clean room" at home (where there are no indoor smoke or particle sources, and possibly an air cleaner is used). - Go to a "cleaner air" shelter (see Appendix A) or possibly out of area *General Population:* - Follow advice for sensitive groups in box above. - Identify potential "cleaner air" shelters in the community (see Appendix A).
Very Unhealthy	Significant aggravation of heart or lung disease, premature mortality in persons with cardiopulmonary disease and the elderly; significant increase in respiratory effects in general population.	*General Population:* should avoid prolonged or heavy exertion - Stay indoors, avoid exertion	*General Population:* If symptomatic, evacuate to cleaner air shelter or leave area, if safe to do so.
Hazardous	Serious aggravation of heart or lung disease, premature mortality in persons with cardiopulmonary disease and the elderly; serious risk of respiratory effects in general population.	*General Population:* should avoid any outdoor activity.	*General Population:* If symptomatic, evacuate to cleaner air shelter or leave area, if safe to do so.

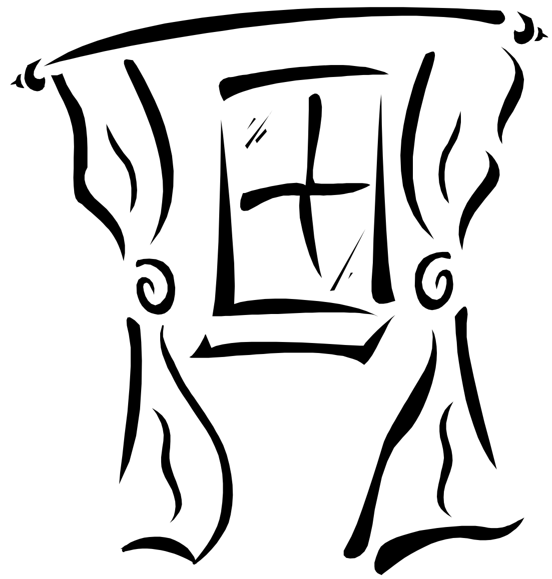
[1] Higher advisory levels automatically incorporate all of the guidance offered at lower levels.

Table 3. Recommended Actions for Public Health Officials

Category	**$PM_{2.5}$ or PM_{10} Levels ($\mu g/m^3$, 1- to 3-hr avg.)**	**Visibility - Arid Conditions (miles)**	**Recommended Actions**
Good	0 - 40	$\geq$ 10	If smoke event forecast, implement communication plan
Moderate	41 - 80	6 – 9	- Issue public service announcements (PSAs) advising public about health effects/symptoms and ways to reduce exposure - Distribute information about exposure avoidance
Unhealthy for Sensitive Groups	81 - 175	3 – 5	- If smoke event projected to be prolonged, evaluate and notify possible sites for clean air shelters - If smoke event projected to be prolonged, prepare evacuation plans
Unhealthy	176 - 300	1.5 - 2.5	- Consider "Smoke Day" for schools (i.e., no school that day), possibly based on school environment and travel considerations - Consider canceling public events, based on public health and travel considerations
Very Unhealthy	301 - 500	1 – 1.25	- Consider closing some or all schools (However, newer schools with a central air cleaning filter may be more protective than older, leakier homes. See "Closures", below) - Cancel outdoor events (e.g., concerts and competitive sports)
Hazardous	> 500	< 0.75	- Close Schools - Cancel outdoor events (e.g., concerts and competitive sports) - Consider closing workplaces not essential to public health - If PM level projected to continue to remain high for a prolonged time, consider evacuation of sensitive populations

Specific strategies

Staying Indoors



The most common advisory issued during a smoke pollution episode is to stay indoors. The usefulness of this strategy depends entirely on how clean the indoor air is. This strategy can usually provide some protection, especially in a tightly closed, air-conditioned house in which the air-conditioner can be set to re-circulate air instead of bringing in outdoor air. Staying inside with the doors and windows closed can usually reduce exposure to ambient air pollution by about a third. In homes without air conditioning, indoor concentrations of fine particles can approach 70 to 100 percent of the outdoor concentrations. In very leaky homes and buildings, the guidance to stay inside with doors and windows closed may offer little protection. If doors and windows are left open, particle levels indoors and outdoors will be about the same.

Increased risk of heat stress is also an important drawback of advising people to stay inside during smoke events. The fire season typically extends from mid-summer through the early fall, when high outside temperatures are common. For individuals who depend on open windows and doors for ventilation, keeping windows and doors closed can be problematic. Older individuals and others in frail health run the risk of heat exhaustion or heat stroke, which could have dire consequences. If outdoor temperatures are very high, it would be prudent to advise those without air conditioning to stay with friends or family who do, go to a cleaner air shelter in their community, or to leave the area. This and other options are discussed below.

Sometimes smoke events can last for several weeks or (rarely) months. These longer events are usually punctuated by periods of relatively clean air. When air quality improves, even temporarily, residents should “air out” their homes to reduce indoor air pollution. People may also wish to clean their residences during such reduced smoke intervals, including mopping, dusting, and vacuuming, in order to reduce subsequent resuspension of particles that may have settled when the smoke was thicker.

Reduced activity

Reducing physical activity is an important and effective strategy to lower the dose of inhaled air pollutants and minimize health risks during a smoke event. During exercise, people can increase their air intake as much as 10 to 20 times their resting level. Increased breathing rates bring more pollution deep into the lungs. Furthermore, while exercising, people tend to breathe through their mouths, bypassing the natural filtering ability of the nasal passages, again delivering more pollution to the lungs. They also tend to breathe more deeply, modifying the normal patterns of particle deposition in the lungs.

Reduce other sources of indoor air pollution

Many indoor sources of air pollution can emit large amounts of the same pollutants present in forest fire smoke. Indoor sources such as burning cigarettes, gas, propane and wood-burning stoves and furnaces, and activities such as cooking, burning candles and incense, and vacuuming can greatly increase the particle levels in a home and should be avoided during high pollution or when wildfire smoke is present. For instance, in a room of 125 square feet, it takes only 10 minutes for the side-stream smoke of 4 cigarettes to create levels of particles in the hazardous ranges (644 micrograms of particles per cubic meter of air or *m*g/m^3). Frying or broiling some foods can produce even higher levels of particles in the kitchen and dining areas. Some of these sources can also increase the levels of polycyclic aromatic hydrocarbons (PAHs), carbon monoxide and nitrogen oxides. Besides cigarette smoke, combustion sources that do not properly vent to the outdoors (including "room-vented" or "vent-free" appliances) contribute most to indoor pollutant levels, and are of greatest concern. Reducing indoor air pollutant emissions during smoke events may reduce indoor particle levels by one quarter to one third or more. Levels of PAHs, volatile organic chemicals (VOCs) and other pollutants can be reduced by even greater proportions. These reductions can help compensate for the increased particle loading from the outdoor air.

Air conditioners

Little is known about the impact of using various types of air conditioners and air filters on indoor air pollutant concentrations. The conventional wisdom is that air conditioners reduce the amount of outdoor particles infiltrating indoors because air-conditioned homes usually have lower air exchange rates than homes that use open windows for ventilation. However, some air conditioners have both "outdoor air" and "re-circulate" settings; these air-conditioners need to be set on "re-circulate". If possible, one should replace the air-conditioner filter with a pleated medium efficiency filter. However, caution must be taken to assure that the system is able to handle the possible increased airflow resistance. Some air conditioners may also be fitted with filters. The more useful are HEPA (High Efficiency Particulate Arrestor) filters, which can capture most of the tiny particles associated with smoke and can further reduce the amount of outside air pollution that gets indoors.

Room air cleaners

Choosing to buy an air cleaner is a decision that ideally should be made ***before*** a smoke emergency occurs. During a smoke emergency, those who require such devices should not be going outside or driving in an attempt to locate an appropriate device, which may be in short supply. It is unlikely that local health officials will be able to buy or supply air cleaners to those who might need them.

Some air cleaners can be effective at reducing indoor particle levels, provided the specific air cleaner is adequately matched to the indoor environment in which it is placed. However, air cleaners tend to be expensive: they are available as either portable units designed to clean the air in a single room ($50 - $300) or as larger central air cleaners intended to clean the whole house ($300 - $1000+). Most air cleaners are not effective at removing gases and odors. The two basic types for particle removal include:

> (a) Mechanical air cleaners, which contain a fiber or fabric filter. The filters need to be sealed tightly in their holders, and cleaned or replaced regularly.
>
> (b) Electronic air cleaners, such as electrostatic precipitators (ESPs) and ionizers. ESPs use a small electrical charge to collect particles from air pulled through the device. Ionizers, or negative ion generators, cause particles to stick to materials (such as carpet and walls) near the device. Electronic air cleaners usually produce small amounts of ozone (a respiratory irritant that can damage lungs) as a byproduct.

The effectiveness of an air cleaner is usually reported in terms of efficiency, which can be misleading, as it only tells half of the story. The other important factor is airflow. Together, these two factors equal the Clean Air Delivery Rate (CADR), which is a better measure of how a device will actually perform. For example, 99.99 percent efficiency sounds great, but if the air exchange rate is only 20 cubic feet per minute (cfm), one would be better off at 90 percent efficiency with 100 cfm air exchange rate (CADR: 20 vs 90 cfm).

Room air cleaner units should be sized to filter at least two or three times the room volume per hour. Most portable units will state on the package the unit's airflow rate, the room size it is suitable for, its particle removal efficiency and perhaps its CADR. Central system air units should handle at least 0.5 air changes per hour, the air exchange rate necessary to reasonably ventilate a house continuously under most conditions.

High and medium efficiency media filters and electrostatic precipitators can be added to central air conditioning systems to keep particle levels in indoor air within acceptable levels during a prolonged smoke event. However, these filters create greater air resistance in the air conditioning system, and may require modifications to the system. In addition, electronic air-cleaners can increase indoor levels of ozone, as noted above.

Devices that remove gases and odors are relatively costly, both to purchase and maintain. They force air through materials such as activated charcoal or alumina coated with potassium permanganate. However, the filtering medium can become quickly overloaded and may need to be replaced often.

For more information about residential air cleaners:
www.epa.gov/iaq/pubs/residair.html
http://www.arb.ca.gov/research/indoor/acdsumm.htm
www.lungusa.org/pub/cleaners/air_clean_toc.html

Ozone generators – a poor choice

Some devices, known as ozone generators, personal ozone devices, "energized oxygen" generators, and "pure air" generators, are sold as air cleaners, but the position of public health agencies, including the California Air Resources Board and US Environmental Protection Agency, is that they do more harm than good. These devices are designed to produce ozone gas to react with pollutants in the air. Ozone is composed of three atoms of oxygen. The third atom can detach from the molecule and reattach to molecules of other substances, altering their chemical composition. It is this ability to react with other substances that forms the basis of the manufacturers' claims.

Ozone, whether in its pure form or mixed with other chemicals, can be harmful to health. When inhaled, ozone can damage the lungs. Relatively low amounts of ozone can irritate the airways, cause coughing, chest pain and tightness, and shortness of breath. It can also worsen chronic respiratory diseases such as asthma, as well as compromise the body's ability to fight respiratory infections. As a result, using an ozone generator during a smoke event may actually increase the adverse health effects from the smoke. In addition, ozone does not remove particles from the air, and would therefore not be effective during smoke events. (Some ozone generators include an ion generator to remove particles, but it would be far safer to buy the ionizer by itself.)

For more information about ozone generators marketed as air cleaners:
www.epa.gov/iaq/pubs/ozonegen.html
http://www.dhs.ca.gov/ps/dcdc/cm/pdf/cm9803pp.pdf.

Humidifiers

Humidifiers are not air cleaners, and will not significantly reduce the amount of particles in the air during a smoke event. Nor will they remove gases like carbon monoxide. However, humidifiers and dehumidifiers (depending on the environment) may slightly reduce pollutants through condensation, absorption and other mechanisms. In an arid environment, one possible benefit of running a humidifier-during a smoke event might be to help the mucus membranes remain comfortably moist, which may reduce eye and airway irritation. However, the usefulness of humidification during a smoke event has not been studied.

Inside vehicles

Individuals can reduce the amount of smoke in their vehicles by keeping the windows and vents closed. However, in hot weather a car's interior can heat up very quickly to temperatures that far exceed those outdoors, and heat-related stress can result. Children and pets should ***never*** be left unattended in a vehicle with the windows closed. The car's ventilation system typically removes a small portion of the particles coming in from outside. Most vehicles can re-circulate the inside air, which will help keep the particle levels lower. Drivers should check the owner's manual and assure that the system is set correctly to minimize entry of outdoor smoke and particles.

Masks

In general, wearing a mask is not an effective exposure reduction strategy during a smoke event. In order for a mask to provide protection, it must be able to filter very small particles (around 0.3 to 0.1 micrometer) and it must fit well, providing an airtight seal around the wearer's mouth and nose. Commonly available paper dust masks, which are designed to filter out larger particles, such as sawdust created by sanding, typically offer little protection. The same is true for bandanas (wet or dry) and tissues held over the mouth and nose. Surgical masks that trap smaller particles are also available, but these masks are designed to filter air coming out of the wearer's mouth, and do not provide a good seal to prevent inhalation of small particles or combustion gases. As a result, these tend to be no better than dust masks. In fact, masks may actually be detrimental, giving the wearers a false sense of security, which may encourage increased physical activity and time spent outdoors, resulting in increased exposures.

There are several additional drawbacks to recommending widespread mask use in an area affected by wildfire smoke. Most people won't use the masks correctly and won't understand the importance of having an airtight seal. For instance, it is impossible to get a good seal on individuals with beards or mustaches. In addition, such masks aren't designed for use by the general public (including children). As a result, masks will provide little, if any, protection.

Masks are uncomfortable (they are more comfortable when they are leaky – but then they do not provide protection). They increase resistance to airflow. This may make breathing more difficult and lead to physiological stress, such as increased respiratory and heart rates. Masks can also contribute to heat stress. Because of this, mask use by those with cardiac and respiratory diseases can be dangerous, and should only be done under a doctor's supervision.

Even healthy adults may find that the increased effort required for breathing makes it uncomfortable to wear a mask for more than short periods of time. Breathing resistance increases with respirator efficiency. A final problem with masks readily available to the public is that they do not filter out harmful irritant gases, such as acrolein or formaldehyde, or other toxic gases, such as carbon monoxide.

There are, however, some situations in which mask use can be beneficial. For outdoor workers, or others who will be outside regardless of the smoke, properly fitted masks can afford some protection. In cases where people are generally staying indoors, wearing a mask to go outside briefly might be useful. Masks can also be used in conjunction with other methods of exposure reduction, including staying indoors, reducing activity, and using HEPA air cleaners to reduce overall smoke exposure.

Some masks (technically called respirators, but they look more like paper masks) are good enough to filter out 95 percent of the particulate matter that is 0.3 micrometers and larger. Smoke particulate matter averages about 0.3 micrometers in diameter, so these masks can filter out a significant portion of the smoke if they are properly fit to the wearer's face. These masks, which may include an exhalation valve, do not require cartridge filters. They are marked with one of the following: "R95", "N95" or "P95." These are typically sold at home improvement stores, and tend to be more expensive than ordinary dust masks. Soft masks with higher ratings (R, N or P99 and R, N, or P100) are also available and will filter out even more particles. As with masks, if a respirator does not provide a tight seal, it will not be effective (see preceding discussion).

Respirators with purple HEPA filters offer the highest protection, but may be less comfortable and slightly more expensive than the flexible masks. Individuals who wish additional protection may purchase tight-fitting respirators that require cartridge filters. Respirator cartridges can be obtained that have a combination N95 or N99 filter with organic vapor backup. This combination can help reduce exposure to some gases, such as benzene and irritant aldehydes, as well as particles. Again, unless there is an airtight seal over the wearer's mouth and nose, such respirators will provide little protection.

Cleaner Air Shelters

Public health officials in areas at risk from forest fires should identify and evaluate cleaner air shelters prior to the fire season. Guidance for identifying and setting up a Cleaner Air Shelter is provided in Appendix A. During severe smoke events, cleaner air shelters can be designated to provide residents with a place to get out of the smoke. Staying inside may not adequately protect sensitive individuals, however, since many houses and apartments do not have air conditioning, and depend on open windows and doors for cooling. Other homes may be so leaky that indoor pollution levels will quickly equal those outside. Cleaner air shelters can be located in large commercial buildings, educational facilities, shopping malls or any place with effective air conditioning and particle filtration.

Closures

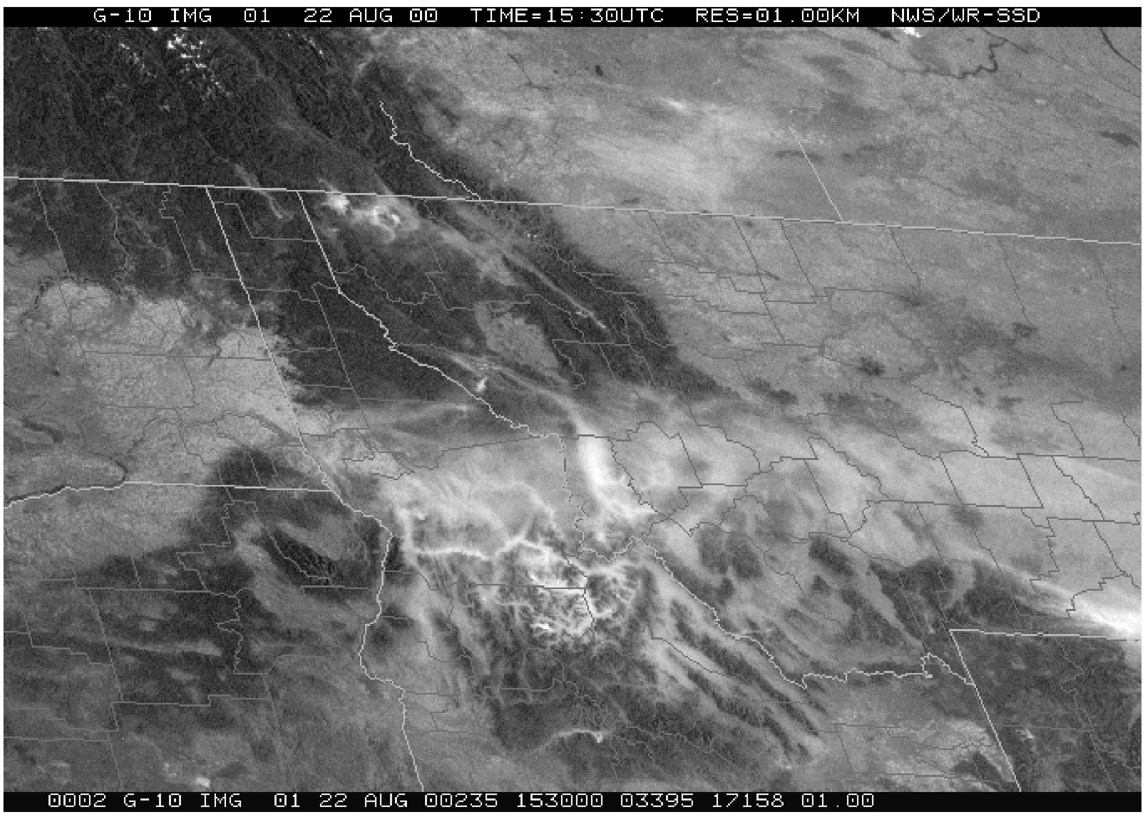
The decision to close or curtail business activities will depend upon predicted smoke levels, and other local conditions. One factor to consider is whether pollutant levels inside schools and businesses are likely to be similar to or lower than those in homes. Children's physical activity may also be better controlled in schools than in homes. On the other hand, in some school districts smoky conditions may make travel to school hazardous. In many areas it will not be practical to close businesses and schools, although partial closures may be beneficial. Closures and cancellations can target specific groups (e.g., the sensitive populations described earlier) or specific, high-risk activities, such as outdoor sporting events and practices. Curtailing outside activities can reduce exposures, as can encouraging people to stay inside and restrict physical activity. A decision to restrict industrial emissions should be based on local air pollution and the emission characteristics of particular industries. Curtailment may not be beneficial if eliminating industrial emissions will not markedly reduce local air pollution.

Evacuation

The most common call for evacuation during a wildfire is due to the direct threat of engulfment by the fire rather than by exposure to smoke. Leaving an area of thick smoke may be a good protective measure for members of sensitive groups, but it is often difficult to predict the duration, intensity and direction of smoke, making this an unattractive option to many people. Even if smoky conditions are expected to continue for weeks, it may not be feasible to evacuate a large percentage of the affected population. Moreover, the process of evacuation can entail serious risks, particularly if poor visibility makes driving hazardous. In these situations, the risks posed by driving with reduced visibility need to be weighed against the potential benefits of evacuation. Therefore, in areas where fires are likely to occur, public health officials are encouraged to develop plans for local protection of sensitive groups.

Characteristics of wildfire smoke

The behavior of smoke depends on many factors, including the fire's size and location, the topography of the area and the weather. Inversions are common in mountainous terrain. Smoke often fills the valleys, where people usually live. Smoke levels are unpredictable: a wind that usually clears out a valley may simply blow more smoke in, or may fan the fires, causing a worse episode the next day. Smoke concentrations change constantly. By the time public health officials can issue a warning or smoke advisory, the smoke may already have cleared. National Weather Service satellite photos, weather and wind forecasts, and knowledge of the area can all help in predicting how much smoke will come into an area, but predictions are rarely accurate for more than a few hours. The National Weather Service's Web site has a lot of information, including satellite photos that are updated throughout the day. For the western United States, the Web address is www.wrh.noaa.gov.



Estimating particulate matter levels

Particulate matter levels are measured as micrograms (μg) of particles per cubic meter of air. Most particle monitoring devices measure particulate matter with a median diameter of 10 micrometers or less (PM_{10}). An increasing number of monitors now measure smaller particles, also known as fine particles, which have median diameters of 2.5 micrometers or less ($PM_{2.5}$). In wildfire smoke, most particles are less than one micrometer, so the values obtained by measuring either PM_{10} or $PM_{2.5}$ are virtually interchangeable, and are treated as such in this document.

Communities with established air quality programs may issue public alerts based on predicted 24-hour average concentrations of particulate matter. Smoke emergencies need to be handled differently, however, as smoke concentrations generally tend to be very high for only a few hours at a time. These short-term peaks may cause some of the most deleterious health effects.

Another factor is public perception. Since smoke is so effective at scattering light, visibility changes drastically as smoke concentrations increase. Even without being told, the public can tell when the smoke is getting worse, and they want authorities to respond to changes as they are happening.

Many communities don't have continuous PM monitoring, and therefore need to estimate particle levels. Continuous PM monitors give an instant reading of particulate matter concentrations. However, visibility can sometimes serve as a good surrogate. Even in areas with monitors, this index can be useful, since smoke levels change constantly and can vary dramatically even between monitors that are near one another. A visibility index gives members of the public a quick way to assess smoke levels for themselves.

Table 1: Estimating particulate matter concentrations from visibility assessment

Categories	**Visibility in Miles**	**Particulate matter levels* (1-hour average, $\mu g/m^3$)**
Good	10 miles and up	0 - 40
Moderate	6 to 9	41 - 80
Unhealthy for Sensitive Groups	3 to 5	81 - 175
Unhealthy	1 1/2 to 2 1/2	176 - 300
Very Unhealthy	1 to 1 1/4	301 - 500
Hazardous	3/4 mile or less	over 500

*In wildfire smoke, most particles are less than one micrometer, so the values obtained by measuring either PM_{10} or $PM_{2.5}$ are virtually interchangeable, and are treated as such in this document. Therefore, in the table above, the different particle levels can be measured using either PM_{10} or $PM_{2.5}$ monitors.

Making personal observations to determine smoke concentrations

- Face away from the sun.
- Determine the limit of your visibility range by looking for targets at known distances (miles). The visible range is the point at which even high-contrast objects (e.g., a dark forested mountain viewed against the sky at noon) totally disappear.
- After determining visibility in miles, use Tables 2 and 3 to identify potential health effects and appropriate cautionary statements.

At times, the visibility index may be hard to use, especially if specific landmarks at known distances are not available for judging distances, or at dawn or dusk. *Furthermore, the above visibility categories for PM levels only apply in dry air conditions. For a given PM level, visibility decreases substantially at relative humidity above 65%, this method of estimation should not be used.* In such cases, individuals may have to rely on common sense in assessing smoke conditions (e.g., mild, moderate, heavy smoke) and the kinds of protective actions that might be necessary. At night or during periods when visibility cannot be used to estimate smoke levels, intense smoky odor may be used to indicate potentially harmful levels.

Additional information on estimating pollutant exposures from smoke can be obtained at **http://www.fs.fed.us/pnw/pubs.htm**, which contains an online version of "Smoke Exposures at Western Wildfires" (PNW-RP-525, July 2000). This link contains a series of photographs relating smoke levels near wildfires with measuring exposures to respirable particles, carbon monoxide, and formaldehyde.

Summary of Strategies for Exposure Reduction

When wildfires are expected to create smoky conditions, people can pursue a number of strategies to reduce their exposure. Those with moderate to severe heart or respiratory disease might consider staying with relatives or friends who live away from the smoke during the fires. If smoke is already present in substantial quantities, such individuals may want to evaluate whether evacuation might actually cause greater exposure than staying at home using other precautions described above.

All people in a smoky area (except firefighters or emergency personnel) should avoid strenuous work or exercise outdoors. They should avoid driving whenever possible. If driving is necessary, people should run the air conditioner on the "recycle" or re-circulate mode to avoid drawing smoky air into the car.

Closing up a building by shutting windows and doors can give some protection from smoke. If the building has air conditioning, its controls should be set in the “recycle” mode, if possible, to prevent smoke-laden air from being drawn into the building.

Once people have closed up the building in which they live or work, they should avoid strenuous activity, which can make them breathe harder and faster. They should drink plenty of fluids to keep their respiratory membranes moist. They may even want to breathe through a moistened washcloth, as long as it does not interfere with their ability to breathe. Dust masks generally do not capture very fine particles and may make it more difficult to breathe, especially for people with chronic lung diseases such as chronic bronchitis or emphysema.

In preparation for the fire season or a smoke event, it is a good idea to have enough food on hand to last several days, so that driving can be minimized. It is also important to have at least a five-day supply of medication for the same reason. Foods stored for use during the fire season should not require cooking, since cooking can add particles to indoor air. Vacuuming should also be avoided, since most vacuum cleaners disperse very fine dust into the air.

If smoke levels increase to very unhealthy or hazardous levels, it may be appropriate for some individuals to stay in a clean room in the home, relocate temporarily to a cleaner air shelter, or to leave the area entirely if it is safe to do so.

Bibliography

California Air Resources Board, Fact Sheet on Air Cleaning Devices and the Home: http://www.arb.ca.gov/research/indoor/acdsumm.htm

Coefield, John and Cyra Cain. 2001. Forest Fire Smoke Categories. Montana Department of Environmental Quality, PO Box 200901, Helena, MT 59620.

Brauer, Michael. 1999. Health Impacts of Biomass Air Pollution. World Health Organization. Background papers for Health Guidelines for Vegetation Fire Events, Lima, Peru, 6-9 October 1998. Available at http://depts.washington.edu/wildfire/

Hansen, E. S. A cohort study on the mortality of firefighters. Br J Ind Med 47: 805-809, 1990.

Jenkins, Peggy and Scott Fruin. 2000. Shelter in Place with Windows and Doors Closed from the Summary of Forest Fire/Prescribed Burning Smoke Meeting. Oakland, California. Available at http://depts.washington.edu/wildfire/

Jenkins, Peggy and Tom Phillips. 2000. Reduce the Use of Indoor Sources from the Summary of Forest Fire/Prescribed Burning Smoke Meeting. Oakland, California. Available at http://depts.washington.edu/wildfire/

Natural Resources Defense Council. 1996. Clean Air and Energy: Air Pollution, Frequently Asked Questions: Particulate Pollution. Based on Breath-Taking: Premature Mortality Due to Particulate Air Pollution in 239 American Cities. Natural Resources Defense Council, 40 West 20th Street, New York, NY 10011. Available at www.nrdc.org/air/pollution/qbreath.asp

Ostermann, Kathryn and Michael Brauer. Chapter 10: Air Quality During Haze Episodes and Its Impact on Health. Available at http://depts.washington.edu/wildfire/

Physicians for Social Responsibility. 1997. Asthma and the Role of Air Pollution: What the Primary Care Physician Should Know. PSR, 1875 Connecticut Ave. NW, Suite 1012, Washington, D.C. 20009. Available at http://www.psr.org/asthmap01.pdf

Smith, Andy. 1999. Handling Air Pollution Episodes: Lessons learned from Big Bar Complex Wildfire. Available at http://depts.washington.edu/wildfire/

U.S. Environmental Protection Agency, 2002. Air quality criteria for particulate matter. Research Triangle Park, NC: National Center for Environmental Assessment – RTP Office; Third External Review Draft. Available at http://www.epa.gov/ncea/partmatt.htm

US Environmental Protection Agency. 2001. Ozone Generators that are Sold as Air Cleaners: An Assessment of Effectiveness and Health Consequences. Available at http://www.epa.gov/iaq/pubs/ozonegen.html.

U.S. Environmental Protection Agency, 2000. The Air Quality Index Guide to Air Quality and Your Health. Research Triangle Park, NC. Available at http://www.epa.gov/airnow/aqibroch/

US Environmental Protection Agency. 1997. Health and Environmental Effects of Particulate Matter. Office of Air and Radiation, Washington, DC, 20460. Available at http://www.epa.gov/rgytgrnj/programs/artd/air/quality/pmhealth.htm

US Environmental Protection Agency. 1990. Residential Air Cleaning Devices: A summary of available information. Office of Air and Radiation, Washington, DC, 20460. EPA 400/1-90-002. Available at http://www.epa.gov/iaq/pubs/residair.html.

Waldman, Jed. 2000. Use of Air Cleaners in Homes, Schools and Worksites in the Summary of Forest Fire/Prescribed Burning Smoke Meeting. Oakland, California. Available at http://depts.washington.edu/wildfire/

Resources/ Links

Montana Department of Environmental Quality:
http://www.deq.state.mt.us/FireUpdates/index.asp
EPA/University of Washington Fire, Smoke and Health Website:
http://www.firesmokehealth.org/
National Fire Weather: **http://www.boi.noaa.gov/firewx.htm**
National Weather Service: **http://www.wrh.noaa.gov/**
National Wildland Fire Information: **http://www.nifc.gov/information.html**
Forest Service Wildland Fire Morning Report: **http://www.fs.fed.us/news/fire/**
Current Map of Large Fires: **http://www.nifc.gov/fireinfo/firemap.html**
Satellite Images of Fires: **http://www.osei.noaa.gov/Events/Fires**
U.S. Environmental Health Protection Agency Air Quality Website:
http://www.epa.gov/airnow/publications.html

Appendix A

Identification of Cleaner Air Shelters for protection from wildfire smoke:

1. Identify one or more facilities with tight-sealing windows and doors and public access (for example, public schools, fire stations, or hospitals). As a rule of thumb, newer buildings will generally be more desirable than older ones.
2. Facilities with a ventilation system able to significantly reduce, or even eliminate, intake of outdoor air are desirable. If possible, reduce the intake of outdoor air by the ventilation system when the building is used as a Cleaner Air Facility. Open the damper and flush the building when the air is clear.
3. At a minimum, a Cleaner Air Shelter should have a central air filtration system that is at least medium or high-efficiency. If needed, filters should be upgraded prior to the fire season, after assuring that the system can handle the increased airflow resistance.
4. Install/inspect a room air cleaner or preferably a central air cleaner with sufficient capability, i.e., a Clean Air Delivery Rate (CADR) that is twice the room volume for room units, or ASHRAE filter efficiency greater than 80% for central air cleaners.* Ensure proper maintenance of air cleaners, keep spare filters on hand, and provide instructions on changing the filter to trained personnel.
5. Assure that the facility can handle the increased cooling load due to high occupancy.
6. Install a properly calibrated carbon monoxide (CO) alarm that has a digital display and battery backup function (available at most hardware stores).
7. Provide a radio for updates on fire status and access to a telephone in case of emergency.

* American Society of Heating, Refrigeration, and Air-conditioning Engineers (ASHRAE) Standard 52.1-1992. "Gravimetric and Dust-Spot Procedures for Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter".

Appendix B

Washington State Department of Health

News Release

For Immediate Release: July 19, 2001 (01-75)

Contacts:	Denise LaFlamme, Environmental Health Assessment	360-236-3174
	Kate Lynch, Communications Office	360-236-4078
	Lori Albert, Okanogan Health Department	509-422-7156

Smoke from forest fires can create problems for asthmatics, others with chronic diseases

OLYMPIA ¾ An early forest fire season and predictions for a drier-than-normal summer can mean trouble for asthmatics and others with chronic lung or heart diseases. Forest fires present health risks for everyone, especially people with lung or heart diseases, whose health can be seriously affected by smoke.

The Okanogan County Health District, where the Thirtymile Fire still continues to burn, has been monitoring smoke in the county, and issued a health warning last week. "We found that air pollution levels from the fire changed radically within hours, depending on weather conditions," said Lori Albert, a health administrator for Okanogan County. "We have been urging residents who have respiratory or heart conditions to take precautions when smoke is present." She added that "so far, remarkably, we have experienced few problems related to smoke in populated areas because of the direction of the wind."

The Department of Health reminds people with asthma to develop an asthma management plan with their physicians. An asthma management plan involves tracking symptoms to determine when to use additional medications or seek further medical treatment. National Institutes of Health has comprehensive information on managing asthma on their Web site: http://www.nhlbi.nih.gov/health/public/lung/index.htm Those with other lung diseases or infections should contact their physicians to learn how to avoid serious complications that may result from forest fires.

Often people who have not been previously diagnosed with lung or heart disease may begin having problems in smoky conditions. Symptoms of potential lung and/or heart problems include chest tightness, chest pain, shortness of breath, or sudden, overwhelming fatigue.

Be prepared: People with asthma, bronchitis, emphysema, and other lung diseases should make sure they are on medication and have at least a five-day supply on hand at all times through fire season. Talk to your doctor about an asthma management plan and stick to it during unusually smoky conditions. Listen for radio and television messages about fires in your area. Keep a supply of non-perishable groceries on hand, especially foods that do not require cooking. In the event of a wildfire, stay indoors and limit your activity. Check for a "recirculation" function on your furnace or air conditioner. If smoke is present, it will be easier to breathe indoors if air is recirculating instead of drawing smoky air from outdoors.

What to do if there is smoke present:

- **Stay inside with windows and doors shut.**
- **Use the recycle or re-circulate mode on the air conditioner in your home or car.**
- **Avoid cooking and vacuuming, which can increase pollutants indoors.**
- **Avoid physical exertion.**
- **Asthmatics should follow their asthma management plan.**
- **Keep at least a five-day supply of medication on hand.**
- **Contact your doctor if you have symptoms such as chest pain, chest tightness, shortness of breath, or severe fatigue. This is important for not only for people with chronic lung or heart disease, but also for individuals who have not been previously diagnosed with such illnesses. Smoke can "unmask" or produce symptoms of such diseases.**
- **Keep airways moist by drinking lots of water. Breathing through a warm, wet washcloth can also help relieve dryness.**
- **A fitted mask (OSHA N95) can be used to reduce smoke exposure unless it interferes with breathing. A dust mask is generally ineffective with smoke.**

###

Prescribed Range Burning in Texas

by: Larry D. White and C. Wayne Hanselka
Extension range specialists, The Texas A & M University System
Reprinted by Texas Parks and Wildlife Department
Texas Agricultural Extension Service, Zerle L. Carpenter, Director, The Texas A & M University System
College Station, Texas
* Reproduced from PWD-BK-W7000-0196-7/91.

Introduction

Fire was a natural ecological factor on most Texas rangelands before European settlement, therefore, native vegetation is well adapted to burning. Fire effectively suppresses most woody plants while encouraging grass and forb growth. However, sound range, livestock and wildlife management must accompany the use of fire if benefits are to be realized.

Prescribed range burning follows guidelines that establish the conditions and manner under which fire will be applied on a specific area to accomplish specific management and ecological objectives. This contrasts with wildfires that can occur any time fuels will burn, often under extremely hazardous conditions. The conditions selected for a prescribed burn (season, vegetational growth stage and weather factors) must be conducive to safe and effective burning. Management objectives determine the fire characteristics needed to maximize benefits, minimize damage and conduct a safe burn.

The most commonly recognized management objectives that can be accomplished by using prescribed fire include:

- Improved pasture accessibility
- Increased production of forage and browse
- Suppression of most brush and cacti species
- Control of selected forbs and/or grass species
- Improved herbaceous composition
- Improved grazing distribution of livestock and wildlife
- Increased available forage and browse
- Improved forage quality and/or palatability
- Increased animal production
- Removal of excessive mulch and debris
- Control of certain parasites and pests
- Improved nutrient cycling

Each management objective requires a particular set of conditions for burning and a specific type of fire to achieve the desired response. Therefore, carefully evaluate objectives before a fire plan is developed.

Different Fires – Different Responses

Plant response after a fire is influenced by the intensity of the fire, condition of plants at the time of the burn and weather conditions and grazing management decisions following the fire. However, fire effects differ depending on rainfall, fuel quantity and length of growing season (figure 1).

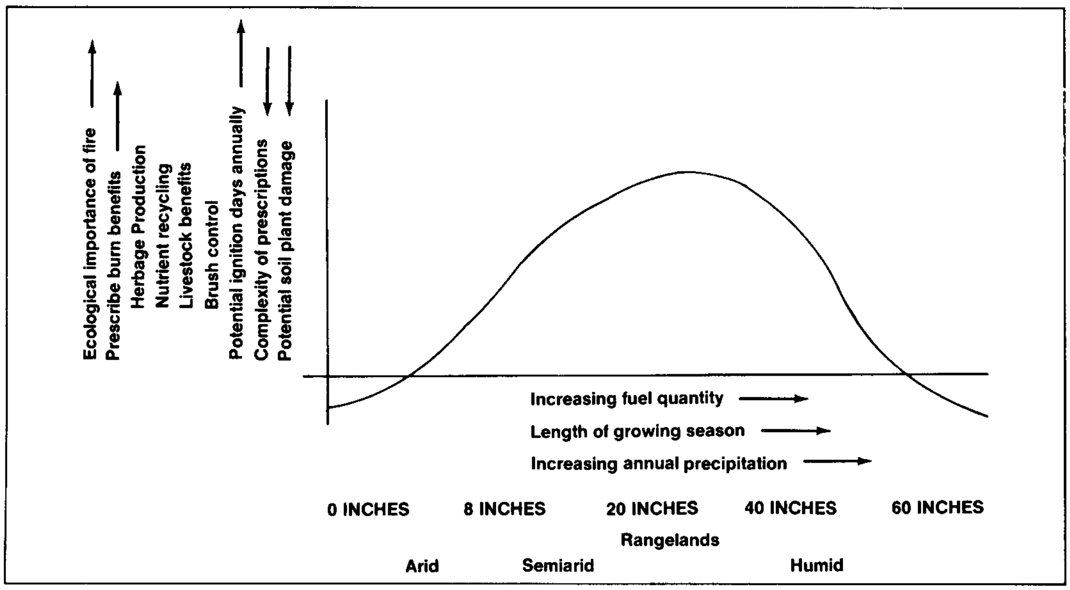


Figure 1. A variety of factors influence the impact of prescribed burning.

Several factors that determine a fire's intensity are fuel quantity and continuity, air temperature, humidity, wind speed, soil moisture and direction of the flame front movement relative to the wind. Generally, the intensity of a fire increases with greater quantity and continuity of fuel, higher temperature and wind speed and lower humidity and soil moisture. A fire set to move in the same direction as the wind (headfire) tends to be more intense than a flame moving against the wind (backfire). Controlling the fire's intensity through correct firing techniques under appropriate conditions is a key factor in achieving the desired responses from a prescribed burn.

An equally important factor to consider when planning a burn to accomplish specific objectives is the stage and type of growth of desirable and target species. For example, the growth stage of forbs at the time of the burn greatly affects the current and following year's production. Forbs are prolific seed producers, but an untimely fire can destroy forb reproduction and wildlife food. Forb seedlings are highly susceptible to fire; therefore, a late winter burn after any annuals have germinated reduces their population. Burns conducted during early to mid-winter with good soil moisture results in late winter annuals and allows rapid recovery of perennials.

Non-sprouting shrubs are easily killed by fires even though the foliage is not consumed (for example, Ashe juniper). Most shrubs sprout from a bud zone at or below the soil surface. These plants are difficult to kill after the seedling stage. However, top kill is often achievable and greatly reduces competition with perennial grasses and forbs for several years. Because of the extensive root system on mature brush plants, sprouts often grow rapidly and produce canopies similar to pre-burn conditions in 3 to 5 years depending on species.

Perennial grasses are better adapted to burning than woody plants and forbs because of differences in location of growing points. For most grasses (during dormancy), the growing points are located near or below the soil surface. Annual grasses may be killed by fire after they germinate but may be promoted if burning occurs before germination. Fires that consume annual grasses before seeds drop greatly reduces next year's seedling production and affects food supplies for some wildlife, such as quail.

The differences in growth cycles between warm and cool season grasses allows timing a burn to enhance one class over the other. Early greenup grasses, such as threeawn, can be harmed by an early spring burn with little damage to deep-rooted perennial grasses. However, cool and wet soil conditions can reduce heat penetration to the sprout zone of shrubs resulting in less damage. Usually, late winter burns improve forage quality, provide rapid grass recovery for earlier grazing, control winter annuals and reduce shrub competition by top removal and seedling kill.

Winter dormant plants recover faster than drought-stressed plants burned during the spring, summer, or fall. Also, summer fires are extremely hot and more damaging to vegetation than winter burns. The vegetation is drought stressed and highly flammable at this time of year. High soil temperatures and low humidity combined with flammable fuels contribute to summer burn intensity. Use summer burns only after careful evaluation and planning. If the burned area remains bare for long periods, the potential for soil erosion is greatly increased.

In summary, much of the prescribed range burning involves the correct combination of firing techniques, seasonal timing and appropriate weather and range conditions on the day of the burn.

However, these are not the only factors that influence plant response after a burn. Precipitation amounts and season received have a significant effect on range recovery following a burn. Grazing management practices are also important in affecting the recovery rate and level of recovery.

Principles for Using Prescribed Fire

A successful burning program involves three basic steps: (1) thorough planning which includes total ranch evaluation, pasture selection, management goals, training for conducting a safe burn and preparations for the burn; (2) safe and effective execution of the burn on the specified area(s); and (3) sound range, livestock and wildlife management before, during and after the burn(s).

The Fire Plan

The fire plan identifies the recommended guidelines, procedures, preparations and resources needed for conducting a burn. The plan should describe ignition procedures, location of control crews and location of firelines. Have a contingency plan for control if the fire should escape. Discuss this with your volunteer fire chief in advance of the burn. Volunteer fire departments should be notified of the burn date(s) and burn plan. Regulations for prescribed burning are controlled by the Texas Air Control Board. Obtain and follow current regulations.

Several points to remember in planning a burn are:

- Preburn grazing management (including wildlife population control) is necessary to allow adequate fuel build-up and improved desirable plant vigor.
- Prescribed burns require adequate preparation, equipment, and experienced personnel.
- Fire plans and prescriptions are only guidelines.
- Fire behavior must be predictable for effective containment.
- Fire intensity is determined by weather, fuel conditions and type of fire.
- The greater the intensity of the fire, the greater the risk of escape.

- Fire primarily topkills perennial plants.
- Vegetation recovery rate is dependent on species, their vigor, fire temperature, weather conditions, and management before and after the burn.
- Postburn management of livestock and wildlife is critical to recovery and improvement of desirable plant species.
- Repeated fires are usually necessary to meet objectives.

Prescribed fire can be used alone or in combination with other range improvement practices (table 1). If sufficient grass fuel cannot be produced, use more intensive practices combined with proper grazing management to promote range improvement. Using fire in combination with other practices often extends longevity and improves the economic rate of return.

Table 1: Relationship between range condition and optimum use of brush management practices.

Range Condition	Percent of Potential	Brush Management Practice
Excellent	100	Prescribed burn
	to	Individual plant treatment
	75	Biological control----------------
Good	74	Roller chop
	to	Individual plant treatment
	50	Prescribed burn
		Biological control
Fair	49	Roller chop and burn
	to	Shred and burn
	25	Chain and burn
		Broadcast herbicide
		Broadcast herbicide & burn
		Biological control
Poor	24	Root plow and seed
	to	Disk seed
	0	Tandem roller chop, seed & burn

Executing the Burn

Consider the day of the burn as judgment day. The first priority is to insure that preparations are complete and check local weather forecasts. The National Weather Service can provide an estimate of conditions during and following the burn. Also measurement of on-site wind speed, wind direction, air temperature and relative humidity are recommended before and during the burn for timely adjustments in procedures.

Only one person (the fire boss) should be in charge of the burn. Identify who the fire boss is to prevent false alarms and unnecessary expense to the fire departments. This person must decide whether to burn and constantly re-evaluate fire behavior, ignition and control during the fire. Even after years of experience, there is always a need for concern and constant alertness. No prescription can be followed to the letter but must be adapted each moment before and during the burning. Before beginning the burn give final notification to volunteer fire departments, sheriff's departments and neighbors. This cannot be overemphasized.

Use small test fires to evaluate fire behavior each time conditions change and adjust the plan as needed. The test fire allows better evaluation of existing conditions and potential outcome of the larger burn before a commitment is made. Changes may be necessary to maintain control or to alter intensity of the fire to accomplish specific management objectives. Once the fuel is burned, the opportunity for that season is gone.

Ignition crews must be constantly aware of fire behavior. The potential for escape is greatest during ignition if current factors are not fully appreciated. Make adjustments immediately for any changes in wind direction, velocity, fuel flammability and relative humidity.

The person igniting the fire must be careful never to allow a heat build-up that can escape. Do not get in a hurry; allow the fire to do its job. Flame heights become dangerous when they reach more than halfway across the fireline. Avoid conditions that carry ignited leaves and ash outside the burn area.

Maintain two-way communication between all personnel. Accurate and rapid communication allows proper decisions and immediate area.

Keep sprayers, along with an accessible water source, readily available for controlling small fires. The need for other equipment such as a dozer, chain saws, handtools and graders will depend on conditions. Everyone on the fire should understand their responsibilities and the burn plan. Only the fire boss should direct the actions on the burn, including control of any escaped fires.

Predicting Fire Behavior

Weather conditions and firing techniques significantly influence fire behavior. The variables most affecting fire behavior are topography, fuels, weather, and firing techniques. These factors may be counteractive, additive, or dominant.

Topography

Topography affects wind behavior and heat build-up which in turn affects flame front movement over the area. Prediction of wind patterns is necessary so that prefire control measures are taken and appropriate firing procedures are used. A fire moves faster upslope and slower downslope when compared to level terrain. Wind is channeled up canyons with increasing speed. In addition, wind in valleys and on slopes moves upward during the day because of surface heating and downward at night because of surface cooling unless prevailing winds are strong enough to overcome local conditions. Eddy currents over the crest of a hill and around objects create different fire intensities, rates of spread and direction of fire front movement. Sometimes these conditions create fire whirlwinds that can carry sparks, burning debris or flames across a normally safe fireline. Firewhirls are small, tornadic winds, like a dust-devil, created from intense hot spots and rapid rising air at a concentration point.

Fuel

Fuel moisture content directly affects ignition and flammability. Green, living tissue is more difficult to ignite than dead material, which ordinarily promotes the spread of fire. Temperature, humidity, wind, precipitation and dew, season, time of day, topographic location and microclimate determine fuel moisture. Completely dried grass crackles and breaks easily into pieces when crushed in the hand, while dry twigs snap. In general, grass fuels are relatively safe to burn, whereas plants with high oil content are explosive and can create serious firebrand problems.

Moisture content of dead grass, leaves and small branches changes quickly with atmospheric moisture, hence they are considered fast burning fuels. Logs, stumps, and large branches, by contrast, take up moisture more slowly. Longer periods of atmospheric drying (several days) are required for prescribed burns to consume logs. Once these fuels have been ignited they may burn for several days. Do not concentrate these fuels near firelines.

The quantity of fuel that burns determines the amount of heat developed during a fire. Generally, 1,500 to 2,000 pounds of grass per acre are required for an effective broadcast burn. The heat generated affects fire characteristics and results. A good grazing management program allows for development of necessary fuel, especially in above average rainfall years.

Weather

Weather conditions before, during and after the burn have a major influence on fuels, conditions, procedures and recovery. Predicting wind speed and direction is necessary so that the fire burns in a predetermined manner. Wind movement can be predicted if burning is conducted with a knowledge of weather systems and the effect of high and low pressure cells. Winds associated with frontal weather systems will shift in a clockwise direction as the front approaches and passes over (figure 2). Wind direction changes quickly as a front moves through an area. The wind in South Texas will be from the southeast shifting to the southwest as a front approaches. In North and West Texas, winds are usually from the southwest shifting to the west. Wind speed increases and is often gusty and turbulent just before the front passes. After passage of the front, the wind direction is usually from the north and may be unstable for some time. After a day or two, the winds will be from the northeast or east. The shape of the front and rate of movement are important. Generally, movement of fronts during the winter causes constantly changing conditions in Texas.

Wind speed greatly affects the flame height, rate of spread and uplift of embers and burning material. Speed must be sufficient to carry fire easily through the fuels but not high enough to cause the fire to jump the downwind firelines. Wind speed should be between 5 and 15 miles per hour for effective burning.

Low wind movement is dangerous because of possible whirlwind development and unpredictable direction of spread. High wind speeds may reduce fuel consumption and increase chances of escape. Wind direction must be consistent throughout the burn to avoid unpredicted fire behavior. Usually, large fires create their own wind around the convection column of smoke, heat and flame front. Two fires moving toward each other can create an intense hot spot or firewhirl.

The height and density of plants affect wind velocity. Unless sufficient fuel occurs within a brush stand, wind velocities may be insufficient to move flames properly and damage the brush. Also fuel should be uniformly distributed and in sufficient quantity to carry the fire under the canopy of a shrub or tree to generate the necessary heat to kill plant tissue. Mechanically cleared firelines and roads in brush or trees create openings that produce unusual wind movements.

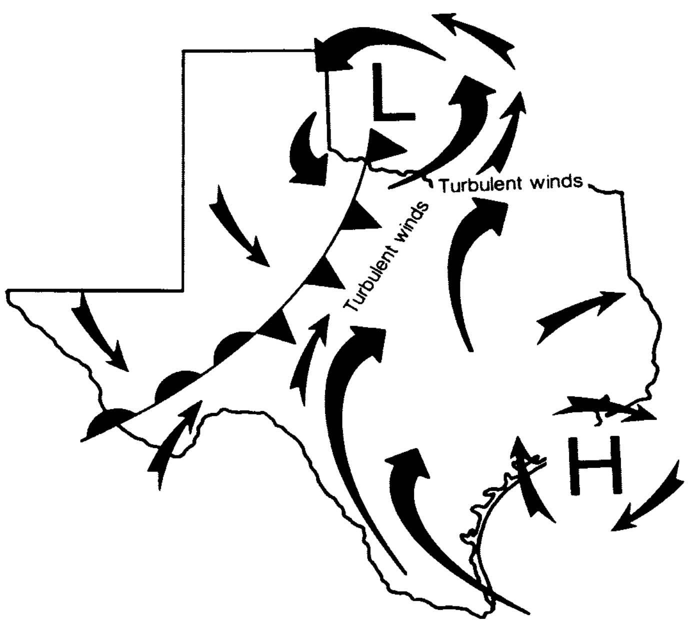


Figure 2. Prevailing wind direction depends on the location of fronts and high and low pressure cells.

Relative humidity affects fuel moisture, fire intensity and rate of spread. The lower the relative humidity, the hotter the fire and the greater the risk. Fine fuels such as grass, burn with the same intensity when relative humidity is between 25 to 45 percent. Cooler fires result when the relative humidity is 45 to 60 percent. Less uniform and intense fires occur when relative humidities are above 60 percent. Do not attempt to burn when relative humidities are below 20 percent.

Day to night changes in air temperature and relative humidity create different fire behavior potentials. Fires of different intensities can be executed by selecting different times of day or night and different weather conditions. The density of a brush stand and the amount of shade created by the vegetation affects the relative humidity near the soil surface. Except under extremely dry conditions, brush stands burn slower and less intensely than open grassland areas.

Firing Techniques

Proper ignition procedures are needed to effectively contain a fire and accomplish management objectives. Ignition procedures greatly influence fire behavior and spread. Fires either move in the same direction as wind (headfire), in an opposite direction of wind (backfire) to at a right angle to the wind (flankfire) (Figure 3). The headfire is the most intense because of its faster rate of spread, wider burning zone and greater flame heights. The flankfire is of intermediate intensity.

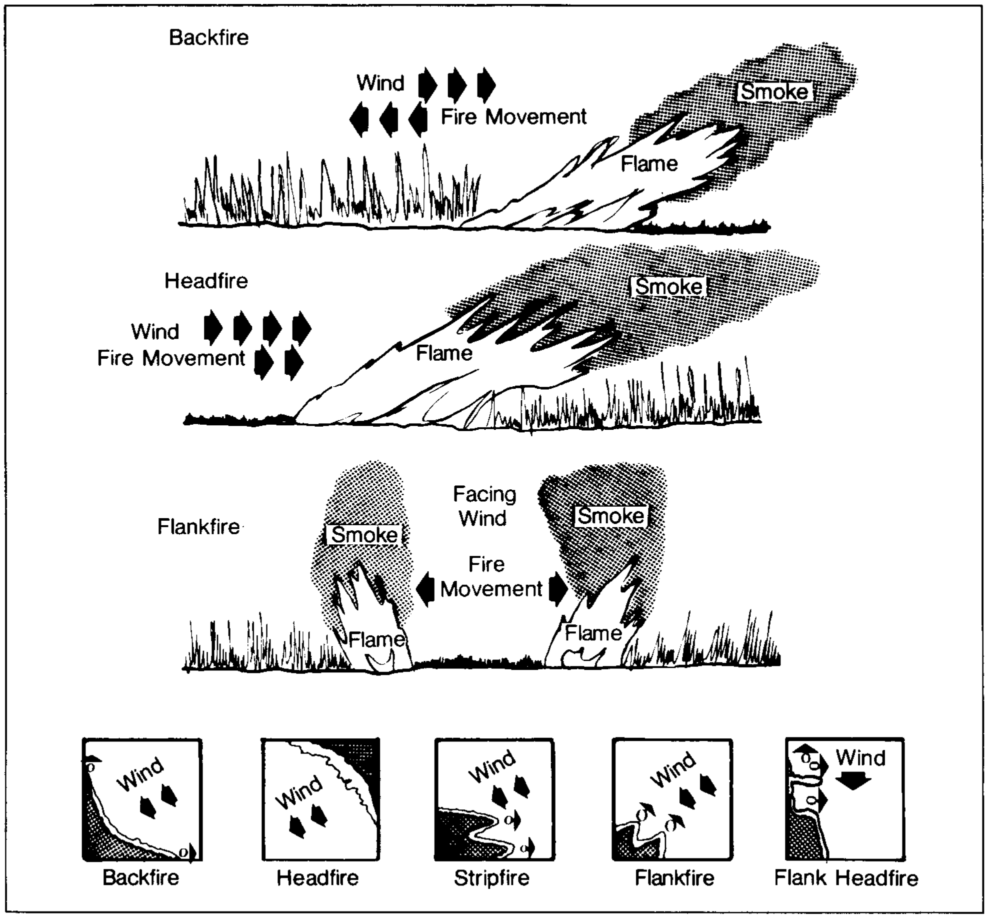


Figure 3. Firing techniques commonly used for prescribed burning.

Backfires require higher fuel quantities and a more continuous fuel distribution than headfires. Since backfires move slower and have a less intense flame front, they are easier to control. Also, in heavy fuels, a backfire may consume more fuel and provide greater plant basal damage to brush than fast moving headfires by keeping heat closer to the soil surface. Set backfires as close to the fireline as possible to prevent high flames and embers from crossing the fireline.

Headfires are effective at top killing shrubs and trees with intense heat several feet above the soil surface. Headfires burn under a wider range of weather and fuel conditions than backfires but are more dangerous. Headfires may be required to burn large acreages in a reasonable amount of time. However, a series of firelines across a pasture can be used to set a number of backfires in a short period. Costs of fireline construction are higher.

A combination of the head and backfiring technique is the stripfire. This is simply a line of fire set within the pasture at right angles to the wind direction. The result is a headfire across the strip and backing fire into the wind. This technique is used to speed up the widening of firelines. The ignition crew should regulate the width of the strip so that the flame front does not leap the fireline or burned out area. Changes in fuel quantity and continuity require appropriate changes in width of the strip fired area.

Once a headfire moves 50 to 100 feet, its major flame front characteristics have developed. A 50 to 100 foot wide stripfire can be set to confirm the necessary width of the fireline before setting the major headfire. Properly station all control crews for this test burn. Do not set a second stripfire or the headfire until the flame-front from the strip has calmed.

Backfiring from a fireline, followed by headfiring, has been successfully used throughout Texas (figures 4 and 5). The backfire plus stripfiring is used to sufficiently widen the downwind fireline before the headfire is ignited. This allows flexibility in wind direction and potentially more suitable burn days during a season than when a plan requires a specific wind direction. Also, adjustments in firing can compensate for shifts in wind direction. Observing backfires and stripfires improves judgment on fireline width, potential escape conditions and flammability before setting the headfire.

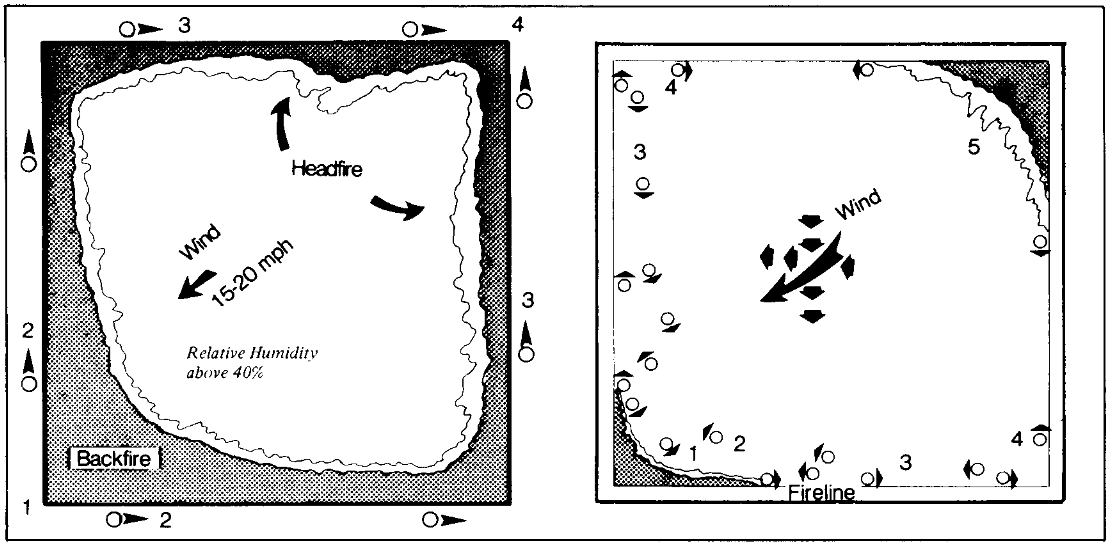


Figure 4. Using combinations of backfiring, stripfiring, flank headfiring and headfiring allows the fireboss and ignition crews to conduct successful burns with fire to help contain the burn. One procedure (left) utilizes a backfire (1) lit simultaneously in each direction. (2) After the backfire has burned 50 to 100 feet on the downwind sides, ignite the remainder of the area (3) and burn as a headfire (4). (From publications by Dr. Henry Wright, Texas Tech Univ.) By using all combinations of firing techniques (right), more difficult burns can be accomplished. The backfire plus narrow strip fires (1) are used to widen the firelines on downwind sides. A wider stripfire is used to increase fireline width and test burnout for containment of the headfire (2 and 3). A flank headfire is used to widen burnout of corners (4). The headfire is set using two torches to the burnout corners (5).

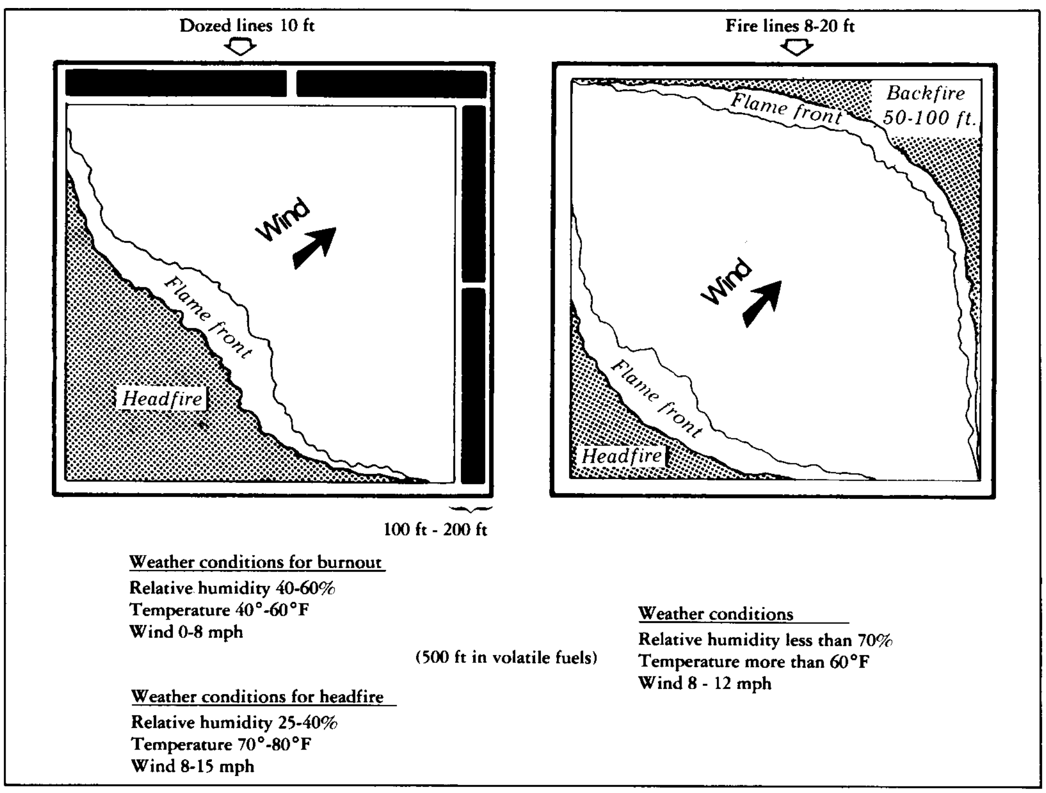


Figure 5. Fire plans and prescriptions differ with objectives, vegetation, personnel training, etc. Fixed wind direction (left) requires burnout of upwind firelines in January and February and ignition of the headfire in February or March. A fire plan using "simultaneous" backfiring and headfiring (right) requires greater coordination and on-the-ground judgment but does not require a fixed wind direction in the prescription. (From publications by Dr. Henry Wright, Texas Tech Univ.)

Fire Containment Practices

Containing a fire to the specified area requires use of natural or man-made breaks in fuel continuity and burning under conditions that minimize chances of escape. Improperly set fires could escape across any fireline. Exercise constant vigilance by personnel throughout all burns. The key to containment is immediate response to any potential escape.

Usually, firelines are constructed using mechanical equipment to expose the mineral soil or by applying fire retardant compounds or water on the fuel. Always plow firelines away from the area to be burned to prevent burying fuel that can smoulder and create sparks for long periods. Usually a fireline 1 to 2 blades wide is adequate, depending on conditions and firing techniques.

Generally, adapt the firing procedure to the kind of firelines and natural barriers available. Use a 1 or 2 foot retardant fireline if care is taken to backfire precisely along the chemical line and not promote flames that can reach flammable fuels. Thus, fire is used under carefully controlled conditions to widen and create a sufficient fireline. Disking is satisfactory if mineral soil is well exposed and flammable fuel is eliminated in the disk strip. Often disking does not adequately destroy the fuel continuity, and use of hand tools or retardants is required to prevent fire from skipping through patches of fuel. Also, disking may reduce accessibility from trucks and sprayers to move quickly along the fireline.

Drip torches (using a diesel-gasoline mixture) are recommended to set uniform, narrow fires without considerable resetting. Burning tires, pear burners and matches are less reliable and create a wider initial flame front. Erratically set fires result in stringers of fire proceeding at different rates drawing each other and creating erratic behavior.

Use special care when burning volatile fuels to prevent embers from crossing firelines. For example, burn juniper poles within 500 feet of the perimeter during the growing season or under high moisture conditions when the surrounding grass is not flammable (figure 6). Use this same practice for any brush pile or concentration of dead fuel that poses a threat to containment. Hot fires under piles will destroy existing vegetation, especially if burned during the growing season. Hand seeding in the ash may be a valuable practice for more rapid recovery.

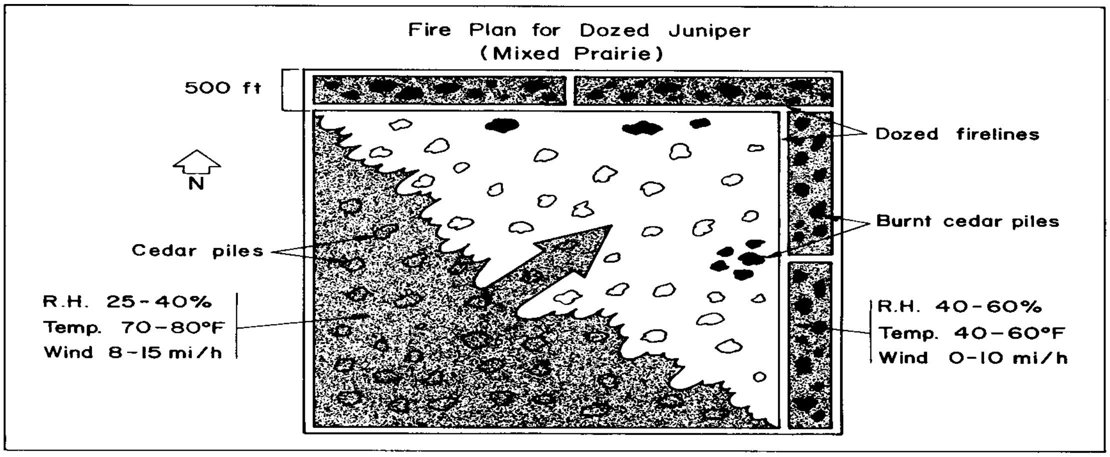


Figure 6. When the grass is green, juniper piles in the 500-foot strip (black splotches) on the downwind sides (north and east) are burned with wind velocities less than 10 miles per hour and relative humidity above 45 percent. Eight months later (when grass is dormant), the grass in the 500-foot strip is burned (strip-headfire technique) when the wind speed is less than 10 miles per hour and relative humidity is between 40 to 60 percent. Lower relative humidities may be used if the grass fuel is less than 2,000 pounds/acre. All large concentrations of piles are backfired on the downwind sides of main area to be burned, and then the entire area is burned into the prepared firelines with a wind speed of 8 to 15 miles per hour and a relative humidity of 25 to 40 percent. (From publications by Dr. Henry Wright, Texas Tech Univ.)

SAFETY IS THE KEY

If it cannot be done safely, do not burn. Escaped fires can damage property, life, equipment, animals and vegetation that negate the beneficial effects achieved with the planned burn.

The fire boss is responsible for executing the burn safely and effectively. Burn plans provide realistic guidelines for when, where, and how to conduct the burn. However, actual burn conditions seldom perfectly match the desired guidelines. Apply techniques that best match the current and expected conditions and use experienced personnel to provide leadership. Do not wear clothing that is highly flammable or melts easily; cotton is recommended.

The landowner using prescribed fire is legally responsible. Arrange for liability insurance and involve neighbors in planning and executing the burn(s). Inform fire and sheriff's departments. Proof of planning and use of accepted burning practices may be invaluable in negating charges of negligence if a fire escapes, resulting in a lawsuit. The Texas Air Control Board in Austin has specific regulations on when and under what weather conditions prescribed burns can be legally conducted. Obtain a copy of the regulations. It is the manager's responsibility to have flagmen on highways to slow traffic if smoke obscures visibility. Generally, fires should move away from highways or houses with a good uplift of smoke. Do not burn when temperature inversions can occur. Ask your weather service if such conditions are likely during the burn and following night.

The bottom line in safety is to have a good plan executed under appropriate conditions with adequate equipment, personnel and preparations. This includes a plan for containing any fire that escapes from the specified area.

BURN PRESCRIPTIONS

Generally, the prescription for a successful burn includes wind speeds of 5 to 15 miles per hour, steady wind direction, air temperature 40 to 80 degrees F., relative humidity 25 to 60 percent and uniform fuel continuity of 1,500 pounds per acre or more. Generally, fire intensity and rate of spread increase with drier fuel, lower RH and higher air temperature, wind speed and fuel quantity.

COSTS OF PRESCRIBED BURNS

The cost of a prescribed burn differs for each ranch, pasture and time of year. Each ranch must develop a budget and keep records of actual expenditures for future analysis. In some counties cost-share assistance is available for fireline construction, labor, and equipment rental. Costs range from 50 cents per acre to $8 to $10 per acre or more depending on fireline construction and manner of calculation. Cost of follow-up should be lower, however.

SUMMARY

Prescribed burning is a viable improvement practice for most Texas rangelands. When integrated with other practices, fire can be used to maintain desired vegetation composition and structure. Many managers are not able to effectively use fire until they achieve better range conditions. Good grazing management programs complement prescribed burning.

The basic principles affecting fire behavior are considered by the manager for developing a realistic fire plan. The fire plan identifies the overall objectives for the ranch as well as for each pasture and range site to be burned. Ideally, burn entire management units to avoid overconcentration of livestock and wildlife. Base the stocking rate on actual acreage burned and adjust for recovery rate. Control white-tailed deer and exotic game populations to prevent overuse of key browse and forb species.

Burning when brush regrowth is young and when fine fuel loads are near maximum can more effectively maintain high production ranges. Brush stands require two to three burns before most objectives are realized. Select the better sites for burning; hence, the net return per dollar invested should be higher.

Described techniques, prescriptions and guidelines provide a basis for using prescribed fire. Consider local experience when adapting prescriptions and plans. Emphasize safety avoid over-optimism. Use fire where benefits can realistically be achieved and integrated with the ranch operation. Take advantage of high forage production years, using excess forage as fuel for a burn. Careful grazing management is an important part of any prescribed burning program.

Assistance and training are available for developing your prescribed burn program. Agencies currently involved are the Texas Agricultural Extension Service, Soil Conservation Service, Texas Forest Service and Texas Parks and Wildlife.

ACKNOWLEDGEMENT

This information was prepared by the Texas Agricultural Extension Service. For more information on range management contact your County Extension Agent.

Prescribed Burning in the South: Trends, Purpose, and Barriers

Terry K. Haines *and* **Rodney L. Busby,** *Room T-10034, USDA Forest Service, Southern Research Station 701 Loyola Ave., New Orleans, LA 70113, and*
David A. Cleaves, *USDA Forest Service, Vegetation Management and Protection Research, Washington, DC 20090.*

ABSTRACT: *The results of a survey of fire management officials concerning historical and projected prescribed burning activity in the South is reported. Prescribed burning programs on USDA Forest Service and private and state-owned lands are described in terms of area burned by ownership and state, intended resource benefits, barriers to expanded burning, and optimum burning area needed to achieve resource management goals. More than 4.1 million aclyr ofpine-type forest were burned between 1985 and 1994, about 6.5% of the area in pine-type forest per year. South. J. Appl. For. 25(4):149–153.*

Key Words: Air quality, endangered species, hazard reduction, ecosystem management, reforestation.

Prescribed burning is a valuable silvicultural tool that has been well accepted by professional forest managers. More than 4.1 million ac/yr of pine-type forest were burned between 1985 and 1994 in the South, about 6.5% of the area in pine-type forest per year. However, despite its ecological and protection benefits, the use of prescribed fire is increasingly subject to constraints such as urban expansion, air quality and other environmental regulations, and liability for smoke intrusions and escaped fires (Craig 1990, Mobley 1990, Cleaves and Haines 1997). The objective of our study was to assess prescribed burning programs on USDA Forest Service and private and state-owned lands in the South.' Annual area and trends in burning for two types of prescribed fire-slash reduction(for site preparation or other postharvest management activity) and underburning of natural fuels beneath an existing overstory, are reported. Forest managers' purposes for burning, barriers to increased burning, and future levels of burning, needed to meet forest management goals are also assessed.

Methods

A questionnaire was mailed to the forest supervisor of each national forest in the South and one representative from each of the 12 southern states' forestry agencies asking them to characterize their respective prescribed burning programs. The questionnaire was reviewed by USDA Forest Service regional fuels managers nationwide prior to distribution to survey respondents in the South.

National forest questionnaires were completed by the national forest fuels management officers. The Ouachita National Forest responses were completed by each of the districts in Oklahoma and Arkansas which we aggregated for the two states response statistics. Otherwise, the forest supervisors distributed the surveys based on their forest's administrative structure. In some cases, forest supervisors distributed the surveys to districts. In others, the fuels manager completed the questionnaires for two national forests which are located within the same state and share the same supervisor's office. National forest fuels managers obtained data from internal prescribed fire activity reports-such as annual prescribed burning accomplishment reports, project work plans, and regional prescribed fire activity reports; some responses were based on personal knowledge.

State agency officials reported data for private and state-owned land. Fuels managers' response data were based on permit and landowner assistance records and personal knowledge. In three states, where data for burning on private lands were not available from the state agencies, telephone contacts were made with prominent industrial and nonindustrial private forest (NIPF) landowners to arrive at an estimate that could be extrapolated.

Survey respondents were asked to provide estimates for the following variables: (1) the average burned area over the period 1985-1994 for two burn types-slash reduction and natural fuels underburning; (2) major intended resource benefits for burning -rated on a scale of importance from 0 (no importance) to 5 (highest importance); (3) historic trends

NOTE: Terry Haines can be reached at (504) 867-9164; Fax: (504) 589-6692; E-mail: tkhforest@aol.com. Manuscript received June 29, 2000, accepted December 5, 2000. This article was written by U.S. Government employees and is therefore in the public domain.

Southern states include Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

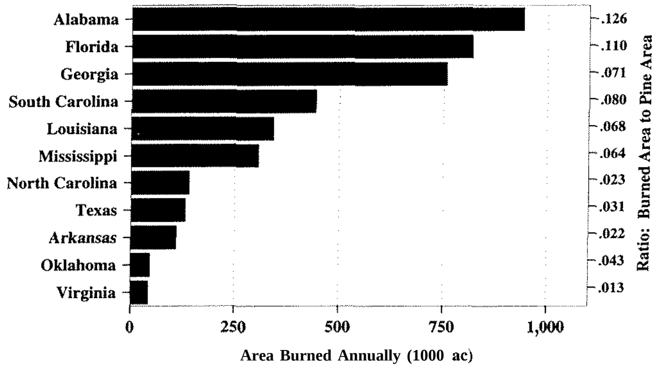


Figure 1. Average annual forestland area burned and ratio of burned area to pine area by state for all ownerships, 1985-1994.

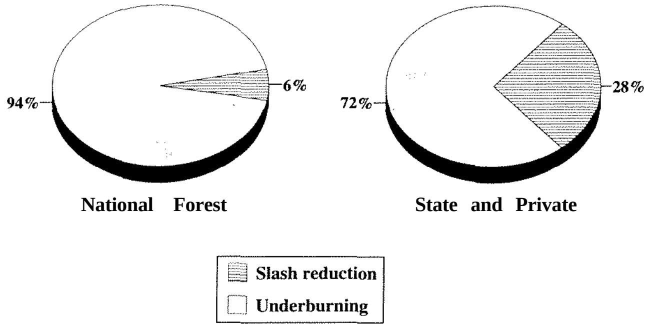


Figure 2. Percent of total area burned annually by ownership and purpose of burn, 1985-1994.

(1985-1994) and expected trends (1994-2004) in burning by burn type; (4) barriers to expanding the use of prescribed fire-rated by importance on a scale of importance from 0 to 5; and (5) annual area of prescribed burning needed to achieve management goals. The response data for variables one through four from each state was weighted by that state's proportion of the total southwide burned area.

Results and Discussion

Activity Levels

Of the reported 4.1 million ac burned on average annually in the 12 southern states, approximately 12% was on national forest lands and 88% on state and private lands. Prescribed burning in four states, Alabama, Florida, Georgia, and South Carolina, comprised 70% of the Southwide area (Figure 1).

A ratio of burned area to the area in pine-type forest was computed for each state based on the state's total area in pine-type forests[2] and the total of the annual area burned as reported by the national forests and state agency officials in each state. The ratio ranged from 0.013 in Virginia to 0.126 in Alabama (Figure 1). Higher burn proportions occurred in the southern Coastal Plain states, Alabama, Florida, Georgia, South Carolina, Louisiana, and Mississippi, where topography and forest resource conditions are most conducive for prescribed burning.

On national forest lands, underburning of natural fuels comprised about 94% of the area burned annually; only 6% of burning was conducted for slash reduction (Figure 2). On private and state lands, about 72% of the area burned was for underburning of natural fuels and 28% slash reduction. Because clearcutting is seldom practiced on national forests in the South and softwood harvest levels have greatly decreased (from 1,162,384 MBF in 1987 to 695,623 MBF in 1994[3]), it is understandable that the national forests reported proportionally smaller slash burn areas. In addition, the prominence of nontimber resources enhanced by fire as a natural ecosystem process, such as longleaf pine restoration and threatened and endangered species would favor more underburning on national forest lands.

From 1985-1994, the Forest Service burned about 12% of its pine-type forestland annually. On private and state lands, only about 6% of the pine-type area was burned each year. Furthermore, based on our state respondents' estimates for area burned for NIPF and industrial ownerships and the USDA Forest Service statistics for area in pine-type forest for the two ownership classes, the ratio of burned area to pine-type area was determined. Industrial landowners burned 2.5 times the rate of NIPF owners across the South; 9% and 3.5%. respectively.[4]

Historical Trends in Prescribed Burning Activity

Because we did not have year-to-year data, we asked respondents to estimate the historical trend for burning over the 10 yrperiod (1985-1994) for the two burn types-slash reduction and natural fuels underburning; whether burning levels had increased, decreased, or remained constant. On national forest lands, 71% of fuels managers reported an increased use of underburning; conversely, 66% reported a decreasing trend in slash reduction burning (Table 1). On private and state lands, trends for both types of burns were fairly constant. About 66% of fuels managers reported that natural fuels underburning was at the same level over the survey period; 58% reported that the area for slash reduction burning had remained constant. Differences in trends in burning for the two ownership categories may be a result of changes in the mix of intended purposes for burning. As

Table 1. Historical trends in prescribed burning levels as reported by state agencies for state and private lands, and national forest fire managersfor national forest lands in the South, 1985-1994, weighted by area.

	Burning purpose			
	Slash reduction		Natural fuels underburning	
T(n = 12)	State and private forests (n = 13)	National forests (n = 12)	State and private forests (n = 12)	National forests (n = 13)
	(%response)*			
Increasing	25	36	14	71
Decreasing	17	63	20	8
No change	58	1	66	21

' Weighted average based upon area burned.

[2] USDA Forest Service, Forest Inventory Statistical Reports for each southern state published by the Southern Forest Experiment Station, Asheville, NC.

[3] USDA Forest Service's annual Cut and Sold Reports (internal document).

[4] Excluding areas burned in Florida: state agency officials could not break out separate statistics for state, industrial, and other private lands or provide estimates.

Table 2. Resources benefiting from prescribed burning as identified by importance ratings (0 = no importance and 5 · highest importance) by fire managers in the South, 1985-1994.

State and private forests (*n* = 12) Resource benefit	Average rating	National forests (n = 13) Resource benefit	Average rating
Hazard reduction	4.42	Hazard reduction	4.94
Reforestation	4.20	Threatened and endangered species	4.92
Vegetation control in established stands	4.03	Game birds and animals	3.72
Game birds and animals	3.70	Reintroduction of fire-ecosystem management	3.12
Nongame wildlife	2.68	Reforestation	2.60
Threatened and endangered species	2.63	Vegetation control in established stands	2.60
Pest protection	2.31	Nongame wildlife	1.84
Reintroduction of fire-ecosystem management	2.27	Pest protection	1.42
Grazing	2.01	Grazing	1.35

previously discussed, the decline in timber harvesting over the survey period could explain the decrease in slash reduction burning on Forest Service lands. Furthermore, the USDA Forest Service survey respondents' comments indicated that the increases in the use of natural fuels underburning on national forest lands reflects the Forest Service's management objective for increased emphasis on longleaf pine ecosystem management and threatened and endangered species habitat management. Private and state lands have not experienced the shifting in purposes for burning that has been occurring on national forest lands. However, a shift from prescribed burning on some industry lands to alternative silvicultural treatments as a result of changing management regimes was reported in one state agency respondents comments.

Resource Management Objectives

The agency representatives surveyed rated nine factors for their importance as resource management objectives from 0 to 5. Resource benefits included hazard reduction, reforestation, vegetation control, habitat enhancement for nongame wildlife, threatened and endangered species, and game bird and animals; insect and disease protection, grazing, and reintroduction of fire into the ecosystem. Hazardous fuels reduction was the highest rated objective for both national forest and private and state lands (Table 2). Game bird and animal habitat management were the third and fourth ranked purpose on national forest and private and state lands, respectively. Other than high ratings for these two purposes, the two ownership categories were more diverse in their purposes. Threatened and endangered species management and the reintroduction of fire into the ecosystem, the second and fourth most important purposes for burning on the national forest, were only of moderate importance for state and private ownerships. Conversely, reforestation and vegetation control, the second and third most important purposes on private and state lands, were only moderately important on national forest lands. The relative importance of burning for these purposes reflects the prominence of private landowners' timber production and harvesting objectives. Prescribed burning for insect and disease control and for grazing enhancement were of low importance in both ownership categories.

Anticipated Future Levels of Prescribed Burning

Survey respondents estimated future trends in burning for the period 1995-2004 for the two burn types by distributing 100 percentage points across three possible categories: "increased burning," "decreased burning," or "the same level of burning" based on the respondents' estimate of the likelihood of each trend. On private and state lands, the expectation for slash reduction burning was about equally split among the three trends; underburning was considered slightly (10 points) more likely to decrease than to increase or remain the same (Table 3).

On national forest lands, slash reduction burning had more than a 50% likelihood of decreasing; while respondents felt very strongly that natural fuels underburning would increase, with a likelihood of 78%. Thus, the shift in burning purposes-from postharvest slash management to fire-dependent ecosystem management and threatened and endangered species habitat improvement is expected to continue. A shift from burning for game habitat management to managing for threatened and endangered species, with an increasing emphasis on plant species recovery was anticipated in the future by several national forest respondents in their comments.

Barriers to Increased Prescribed Burning

Respondents rated 14 factors for their importance as barriers to the expanding the use of prescribed burning. These barriers included: (1) negative public opinion, (2) close proximity of residential development, (3) planning costs, (4)

Table 3. Predicted trends in prescribed burning levels as reported by state agencies for state and private lands, and national forest fire managersfor national forest lands in the South, 1995-2004, weighted by area.

	Burning purpose			
	Slash reduction		Natural fuels underburning	
Trend	State and private forests (*n* = 12)	National forests *n*= 13)	State and private forests (*n* = 12)	National forests (*n* = 13)
	···(% o response)*			
Increasing	31	20	33	78
Decreasing	35	55	43	7
No change	34	25	24	15

* Weighted average based upon area burned.

Table 4. Barriers to increased burning as identified by importance ratings (0 = no importance and 5 = highest importance) by fire managers in the South, 1985-1994.

State and private forests (n = 12)		National forests (n = 13)	
Barrier	Average rating	Barrier	Average rating
Public opinion	4.65	Air quality and smoke regulations	4.71
Risk of liability	4.54	Shortage of personnel	4.10
Air quality and smoke regulations	4.12	Risk of liability	3.91
Residential development	4.08	Narrow time frame in which prescribed burning is possible	3.45
Cost limitations	3.87	Lack of funding	3.42
Narrow time frame in which prescribed burning is possible	3.57	Residential development	3.06
Insurance availability	2.83	Public opinion	2.70
Shortages of personnel	2.79	Cost limitations	1.78
Lack of funding	2.65	Heavy fuel loading	1.53
Environmental regulations, not including air quality	2.58	Management policies that discourage risk taking	1.52
Heavy fuel loading	2.34	Environmental regulations, not including air quality	1.48
Management policies that discourage risk taking	2.33	Not certain about the benefits of prescribed burning	0.44
Alternative silvicultural methods are preferred	1.80	Alternative silvicultural methods are preferred	0.29
Not certain about the benefits of prescribed burning	0.86	Insurance availability	0.07

funding limitations, (5) availability of alternative silvicultural tools, (6) air quality and smoke management laws, (7) other environmental laws-excluding air quality and smoke management, (8) risk of liability for smoke intrusions and escaped fires, (9) high cost or lack of insurance availability, (10) agency or company policies that are risk-averse, (11) lack of qualified professionals and technicians, (12) excessive fuel loading, (13) a narrow prescription window for conducting burns, and (14) uncertainty about burning as an effect fuels management practice.

Two barriers, airquality and smoke management laws and risk of liability, were among the four most highly rated barriers by both the national forest and state fuels managers (Table 4). Negative public opinion and residential development in close proximity to areas in need of burning were among the top four barriers on state and private ownerships. On national forest lands, the shortage of qualified personnel was the second most important barrier. A narrow available burning window and inadequate funding were also highly rated barriers on national forest lands.

Comments provided by USDA Forest Service respondents provided additional insight regarding barriers to burning. A "Catch-22" situation was reported in some states due to a clash between USDA Forest Service burning objectives and state prescribed burning guidelines. For example, an objective of the USDA Forest Service fire program is to restore habitat for the red-cockaded woodpecker; however, smoke management guidelines are limiting managers' ability to approach their goals in some states. In addition, USDA Forest Service respondents comments included specific fire-related cost barriers for monitoring burns, conducting archeological surveys, and training employees. State agency respondents comments included the concern that liability issues and public perception are limiting private landowners willingness to burn (more so than on government-owned lands).

Desired Levels of Prescribed Burning

Fuels managers were asked to estimate the annual area that should be burned to achieve their goals based on the mix of resource management purposes described in the survey. The Forest Service burned about 63% of the fuels managers self-described optimum targets compared to 48% on private and state lands.

Projected prescribed fire treatment needed to achieve managers' goals on Forest Service lands was about 750,000 ac/yr. On private and state lands, nearly 7.5 million ac/yr would be burned.

Implications and Opportunities

The Forest Service fuel management budget increased from an average of about $10.5 million from 1985 to 1994 to $70 million in 2000.[5] Without fiscal constraints expected by the respondents, the Forest Service's goal of burning 750,000 ac annually in the South may be more feasible than respondents anticipate. Furthermore, this goal will likely be more attainable if funding is used to recruit and train qualified personnel; the second most important barrier to burning identified by national forest respondents. In fact, since 1997, fuels treatment (primarily prescribed fire) on national forests in the South has approached this goal; fuels treatment accomplishments have risen to 700,000 ac/yr. However, it is unclear to what extent burning levels can continue to increase or be maintained in light of other barriers such as regulatory and liability constraints, residential development, and narrow prescription windows for burning. Respondents comments indicated that these barriers were severe enough in some state's national forests as to diminish the likelihood of achieving managers' prescribed burning goals.

[5] Annual budget data from USDA Forest Service internal reports (Washington DC.).

Survey results indicate that there is a great unmet need for increased burning on state and private lands. State agency fuels managers reported that 7.5 million ac/yr; more than twice current burning levels, should be burned. State holdings comprise only a fraction of the pine-type forest in the South; therefore, activity on these lands would have little impact on the total state and private burning program. Furthermore, burning on industrial lands appears to be fairly aggressive; 2.5 times the rate of burning (burned area per pine-type area) on NIPF lands. In addition, the NIPF area in pine-type forest is almost twice that of industry holdings and ten times the pine-type area in the national forest.

Several factors may explain the gap for prescribed fire treatment on NIPF lands. State agency assistance is particularly important in areas where contractors are not available or willing to conduct prescribed bums. In some states, program funding is insufficient to adequately provide landowner assistance for burning. In other states, agency policies limit landowner assistance to burn plan development, plowing firelines and/or providing emergency equipment on site in the event of a fire escape; agency personnel will not execute the burn for the landowner. In addition, according to survey respondents, liability for escaped fires and smoke and public acceptance are also highly important influences to burning on NIPF lands.

Future research should more fully explore the social, legal, and economic barriers to prescribed burning identified by survey respondents. In addition, better data is needed to fully characterize the use of prescribed fire in the South. Some respondents did not have complete records for burned area over the survey period and in some states, ownership class was not a component included in their records. A uniform, comprehensive system of data collection for burned area, resource management targets, and other elements of burning would facilitate progress on national goals for fire protection and identification of treatment opportunities.

Literature Cited

CLEAVES, D.A., AND T.K. HAINES. 1997. Regulation and liability risk: Their influence on the practice and the price tag of prescribed burning. P. 165–183 in Proc. Environmental regulation and prescribed fire, legal and social challenges, D. Bryan (ed.). Florida State Univ., Tallahassee, FL.

CRAIG, J.N. 1990. Regulation of prescribed fire. P. 261-267 in Natural and prescribed fire in Pacific Northwest forests, Walstad, J.D., et al. (eds.). Oregon State University Press, Corvallis, OR.

MOBLEY, H.E. 1990. Summary of smoke related accidents in the South from prescribed fires. Am. Pulpwood Assoc. Tech. Rel. 90-R-1 1. 2 p.

EFFECTS OF PRESCRIBED BURNING ON VEGETATION AND FUEL LOADING IN THREE EAST TEXAS STATE PARKS

Sandra Rideout and Brian P. Oswald
USDA Forest Service, Forestry Sciences Laboratory
320 Green Street, Athens, Georgia 30602-2044 and
Silviculture and Range Management, Stephen F. Austin State University
Box 6109, SFA Station, Nacogdoches, Texas 75961-6109

Abstract.-This study was conducted to evaluate the initial effectiveness of prescribed burning in the ecological restoration of forests within selected parks in east Texas. Twenty-four permanent plots were installed to monitor fuel loads, overstory, sapling, seedling, shrub and herbaceous layers within bum and control units of Mission Tejas, Tyler and Village Creek state parks. Measurements were taken during the summers of 1999 and 2000. Prescribed burning was conducted between these sampling periods in early spring 2000. Results indicated that the current applications of prescribed burning do not significantly influence vegetation or fuels. Sustained drought, prior management practices and imposed local bum bans reduced the window within which prescribed bums could be applied, and limited the effectiveness of the burns.

Historically, fire has played an important role in most terrestrial ecosystems. Fire has an influence in such ecosystem components as recycling of nutrients, regulating plant succession and wildlife habitat, maintaining biological diversity, reducing biomass, and controlling insect and disease populations (Mutch 1994).

When conducted properly, prescribed fire undoubtedly alters the composition and structure of the understory vegetation within forests. Several subclimax communities and endangered species of Texas are dependent on fire. For example, fire is an essential element in the restoration and management of longleaf pine (***Pinus palustris*** Mill.) stands and pitcher plant ***(Sarracenia** alata* Wood) wetland ecosystems. These and other communities benefit from an active prescribed burning program (Reeves & Corbin 1985).

Prescribed burning is currently used as a management tool in several Texas state parks for the purposes of reducing forest fuels, improving wildlife habitat, altering the composition and structure of the understory vegetation and enhancing park appearances. This study was conducted to evaluate the initial effectiveness of prescribed burning in the ecological restoration of forests and consisted of monitoring pre- and post-burn vegetative characteristics and fuel loads at three Texas state parks. At Mission Tejas State Historical Park, Tyler State Park and Village Creek State Park, 24 plots, eight in each park, were monitored in the summers of 1999 and 2000 to determine short-term ecological effects of pre-scribed burning on vegetation and fuel loads.

METHODOLOGY

The three parks surveyed in this study were all part of the Piney-woods Region of Texas Parks and Wildlife Department's Parks and Historic Sites. Mission Tejas and Tyler State Parks had similar ecological characteristics. Typical overstory species within the burn units of these parks included shortleaf pine (*Pinus echinata* Mill.), loblolly pine (*Pinus taeda* L.), sweetgum (*Liquidambar styraciflua* L.), water oak (Quercus *nigra* L.), white oak (Q. *alba* L.), mockernut hickory (*Carya tomentosa* (Poir .) Nutt .), white ash (*Fraxinus americana* L.) and American holly (*Ilex opaca* Ait.). Common understory species included yaupon (*Ilex vomitoria* Ait.), flowering dogwood (*Cornus florida* L.), American beautyberry (*Callicarpa americana* L.), longleaf uniola (*Chasmanthium laxum* var. *sessiliflorum* (L.) Yates), panicums (*Panicurn* sp.) and various sedges (Texas Parks and Wildlife 2000a; Texas Parks and Wildlife 2000b).

Average low temperatures in January range from 0 to 2°C, while July averages highs of 34 to 36°C. The first and last freezes typically occur around mid to late November and mid March to early April, respectively. Average rainfall exceeds 100 cm per year (Texas Parks and Wildlife 2000a; Texas Parks and Wildlife 2000b). Steep slopes abound in these parks, with elevation changes of 100 m within both parks (Texas Parks and Wildlife 2000a; Texas Parks and Wildlife 2000b; Robinson & Blair 1997). The historic fire return interval where these parks are located was 4 to 6 years. It is presently greater than 20 years (Jurney 2000) due to suppression, fragmentation and urbanization of the surrounding areas. Heavy fuel loads persist throughout the park due to decades of sporadic use of fire.

Unlike the others, Village Creek State Park included cypress swamps, bottomland wetlands and blackwater sloughs in the flood plain of the Neches River. The burn unit was once a longleaf/little bluestem (*Schizachyrium scoparium* (Michx.) Nash.) stand. Due to fire exclusion it was being overtaken by broadleaf trees, such as water tupelo (*Nyssa aquatica* L.), river birch (*Betula nigra* L.), water oak and redbay

(*Persea borbonia* (L.) Spreng.), in addition to the invasive Chinese tallowtree *(Supium sebiferum* (L.) Roxb.). Common understory vegetative species included yaupon, flowering dogwood, American beautyberry, poison ivy *(Toxicodendron radicans* (L.) Kuntze), little bluestem, panicums and various sedges. The park's mean elevation was 7 m. January's average low temperature was 3°C, while July's average high was 34°C (Texas Parks and Wildlife 2000c). Historic fire return interval in the area was 1 to 3 years. Now it is greater than 20 years (Jurney 2000).

Methods for establishing plots, and sampling vegetation and fuel loads were as defined in the *National Park Service Western Region Fire Monitoring Handbook* (Western Region Prescribed and Natural Fire Monitoring Task Force 1992). Plot size and sampling locations varied for each monitoring variable. Consistent sample areas were used between plots for each variable. The entire 20 by 50 m rectangular plot was used for sampling overstory (Figure 1). Overstory trees were defined as all trees, living or dead, with dbh > 15 cm. Dbh (diameter at breast height) was defined as diameter outside bark at 1.4 m.

Saplings were defined as standing living or dead trees with dbh ≥ 2.5 cm and ≤ 15 cm. They were sampled only within Quarter 1. Seedlings were defined as those living trees with dbh < 2.5 cm. Seedlings were monitored only in the 5 by 10 m medial section of Quarter 1.

The point line-intercept method was used for sampling shrub and herbaceous layers. The point line-intercept transect ran along the Q4-Q1 50 m line delineating that outside long axis of the plot. Height of the tallest living or dead individual by species, and species from tallest to shortest intercepting the transect were recorded.

To obtain shrub density, the Q4-Q1 transect was widened to a belt 0.5 m wide. A stem count of shrub species within the belt was recorded. To measure density of herbaceous plants, a 1 m^2 frame was placed on the plot side of both outer 50 m transects every 10 meters. The total area sampled in each plot using this method was 10 m^2. Herbaceous species and number of stems were recorded.

Four transects extending 15.2 m in random directions from the centerline at the 10, 20, 30 and 40 m marks in each plot were used to measure fuel loads (Brown et al. 1982). One-, ten-, hundred- and

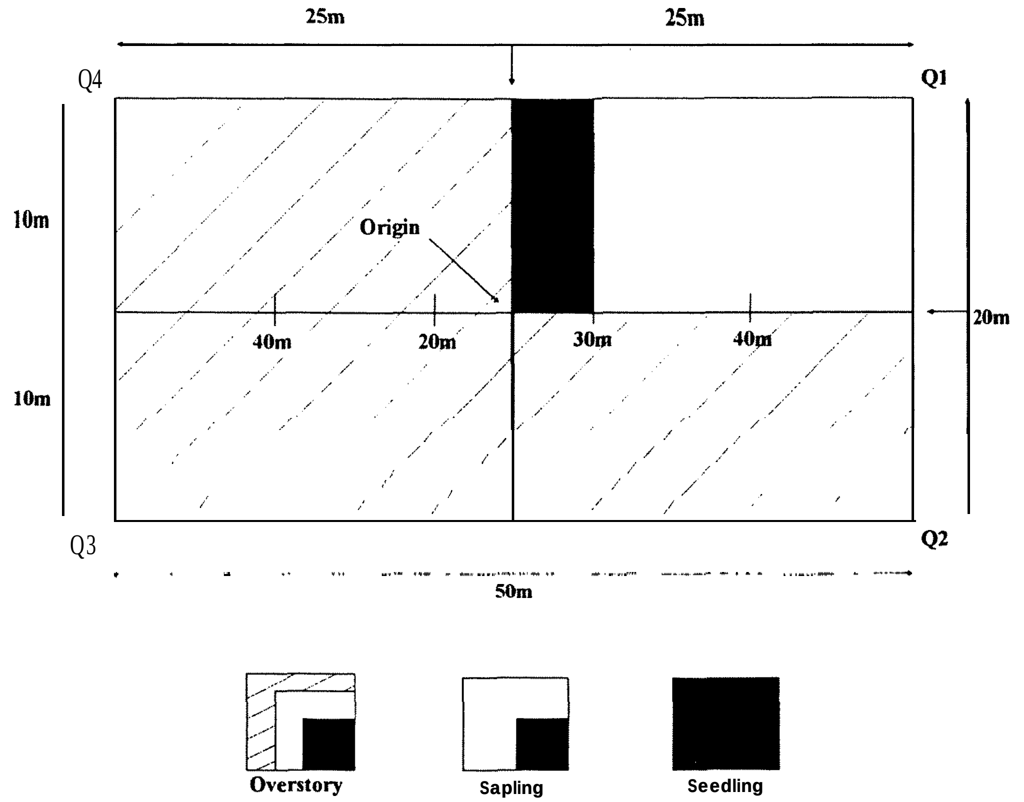


Figure 1. Sampling areas and transects for vegetation and fuel load monitoring (Western Region Prescribed and Natural Fire Monitoring Task Force 1992).

thousand-hour fuels were sampled along these transects. Depth of O_i and O_e (litter) horizons combined was also measured, as well as, depth of 0, (duff) horizon. Samples of O_i and 0, horizons combined were collected and dried to determine litter weight. All vegetative and fuel load monitoring techniques were repeated during the same time of the year 2000.

Texas Parks and Wildlife Department (TPWD) personnel produced the burn plans. Prescribed burns were conducted during late February to early March 2000 when weather and fuel moisture conditions allowed.

To estimate the intensity of each burn, four tiles with heat-sensitive paint were attached to the center t-post of each plot. One tile each was placed 15 cm below ground, at ground level, 30 cm and 61 cm above ground. Tiles were removed immediately after the burn. Analyses of the tiles allowed an estimate within 38°C of the fire temperature at plot origin.

County burn bans prohibited burning in the parks until they were temporarily lifted following rain episodes. Because of the necessity to wait until a rain event, fuels were wet and resulting burns were weak and spotty. Firelines were monitored for two hours after each burn was completed. Park staff was responsible for monitoring the burn unit after that time.

According to written burn plans (Sparks 1999a; Sparks 1999b; Robinson & Blair 1997), the primary objectives of the initial burns were to reintroduce the natural role of fire into the ecosystems and to reduce fuel loads. Other objectives mentioned included reducing risk of wildfire, increasing species richness and diversity, increasing wildlife habitat for numerous species, encouraging longleaf pine seedlings at Village Creek State Park and beginning the first stage in restoration. Cool season burns were recommended every two years to reduce fuels sufficiently for growing season burns. Following three cool season burn cycles, burns would be conducted once every three years during the early to mid-growing season to increase mortality in understory hardwood sapl ings .

Fuel loading (Mg ha-‘) was calculated using Excel software. *ANOVA* and paired t-tests were performed to test for significant differences in pre- and post-burn fuel loads and vegetation in SPSS Base 10.0 (SPSS Inc. 1999). Exploratory analysis was conducted on data in PC-ORD (McCune & Mefford 1999) using twinspan, Detrended Correspondence Analysis (DCA) and graphing the DCA. DCA was designed for ecological data sets. It is based on samples and species, and ordinates both simultaneously (McCune & Mefford 1999).

Paired t-tests were conducted in Excel on overstory and sapling vegetation to determine differences in standing dead vegetation before and after the burns. Morisita's index of similarities was conducted on seedling, shrub and herbaceous communities to determine differences in composition before and after the burns (Morisita 1959). Morisita's index was formulated as follows:

$$C_M = \frac{2\sum X_i Y_i}{(S_A + S_B) N_A N_B}$$

Where: X_i = Number of species i in community A

Y_i = Number of species i in community B

$$N_A = \sum X_i$$

$$N_B = \sum Y_i$$

$$S_A = \frac{\sum [X_i(X_i - 1)]}{N_A (N_A - 1)}$$

$$S_B = \frac{\sum [Y_i(Y_i - 1)]}{N_B (N_B - 1)}$$

RESULTS AND DISCUSSION

Fuel loading results for all parks combined in 1999 (before burning) and 2000 (after burning), indicated a statistically significant reduction in one-hour fuels in burn plots in 2000; however, the actual difference was only 0.05 Mg ha-‘. This is not ecologically significant. There was also a statistically significant reduction in ten-hour fuels in the control plots, while there was no change in the burn plots (Table 1).

The only statistically significant difference in hundred- or thousand-hour fuels was an increase in thousand-hour fuels in control plots (Table 1). Larger fuels may have increased due to drought-stressed trees dying and falling.

For all parks combined, O_i and 0, horizons’ combined weight decreased significantly (t = 5.182, $P < 0.001$) in the burn plots while it did not in the control plots (Table 2). The actual decrease in the burn plots was 0.98 Mg ha^{-1}. There was also a statistically significant decrease in depth of O_i and 0, combined in the burn plots (t = 2.074, $P < 0.05$), while there was a significant increase in the control plots (t = (6.641, $P < 0.001$)(Table 2).

Tiles recovered from the burns indicated weak burns at all parks, with Mission Tejas generally burning hotter than Tyler and Village Creek. Tiles showed no effect from the heat of the burns at the 61 cm (2 ft) level in any plot. One tile at Mission Tejas indicated 93°C at the 30 cm

Table 1. Mean fuel loads and paired r-test results for fuels in 1999 (pre-burn) and 2000 (post-burn) in Mission Tejas, Tyler and Village Creek State Parks combined.

Plot type	Measurement	One-hour	Ten-hour	Hundred-hour	Thousand-hour	Total
Burn	1999 fuel load (Mg ha-‘)	0.29	I.78	1.81	1.63	5.53
(n = 60, *df* = 59)	2000 fuel load (Mg ha-‘)	0.24	1.58	2.49	2.42	6.68
	Mean difference	0.05	0.19	-0.68	-0.79	-1.15
	SD	0.15	2.17	3.73	4.88	5.52
	t	2.453	0.687	-1.406	-1.254	-1.608
	Significance	0.017	0.495	0.165	0.215	0.113
Control	1999 fuel load (Mg ha-‘)	0.31	2.25	1.74	2.55	6.84
(*n* = 36, *df* = 35)	2000 fuel load (Mg ha“)	0.24	1.01	2.04	6.20	9.50
	Mean difference	0.07	1.23	-0.30	-3.64	-2.50
	SD	0.28	1.60	3.30	9.58	10.04
	t	1.518	4.610	-0.553	-2.282	-1.584
	Significance	0.138	<0.001	0.584	0.029	0.122

Table 2. Mean measurements in 1999 and 2000 and paired r-test results for O_i and O_e combined and O_a horizons in Mission Tejas, Tyler and Village Creek State Parks combined.

Plot depth type	Measurement	O_i and O_e weight (Mg ha-‘)	O_i and O_e depth (cm)	O_a (cm)
Bum (*n** = 60, *df* = 59)	1999	2.990	1.348	1.431
	2000	2.015	1.203	1.353
	Mean difference	0.976	0.145	0.077
	SD	1.409	0.542	0.550
	t	5.182	2.074	1.084
	Significance	<0.001	0.042	0.283
Control (n = 36, *df* = 35)	1999	3.716	1.492	1.571
	2000	3.480	2.196	1.600
	Mean difference	0.236	-0.703	-0.029
	SD	1.664	0.636	0.742
	t	0.850	-6.641	-0.234
	Significance	0.401	co.001	0.817

* n = 56 for O_i and O_e weight in the bum plots, *df* = 55 for O_i and O_e weight in the bum plots.

(1 ft) level, while the others recorded no effect. At ground level, tiles indicated a range of intensities from 0°C to 538°C, with Mission Tejas averaging 293°C, Tyler averaging 149°C, and Village Creek averaging 45°C. At the subground level Mission Tejas averaged 197°C and Tyler

averaged 13°C, while tiles at Village Creek recorded no effect. This level of intensity could leave quite a bit of the 0 horizon and downed woody fuels unburned. After the fires, most surface fuels appeared charred but unconsumed.

It appears the burns did not fully reach the objective of reducing fuel loads. The only ecologically important effects were the decreases in weight and depth of the O_i and 0, horizons in the burn plots. The loss in weight from 1999 to 2000 was 0.98 Mg ha-‘, and the difference in depth between the burn and control plots in 2000 was 0.85 cm. These differences were possibly enough to affect the viability of seedlings or herbaceous plants.

VEGETATION

Mission Tejas State Historical Park.-With Axis 1 of the DCA graph representing decreasing time since prior disturbance, one plot was separated to the far right of the other plots in most vegetation classes because it had been burned in the past. There were no records of how long ago the burn occurred. The authors estimated it to be between five and ten years. The plot was very thick with loblolly saplings ranging between one and three inches in diameter.

In both 1999 and 2000, the overstory of Mission Tejas plots was dominated by shortleaf pine followed by sweetgum and loblolly pine. There was not a statistically significant change in number of dead standing overstory or sapling trees from 1999 to 2000. Saplings were dominated by shortleaf and loblolly pines, followed by white oak.

Morisita's similarity index showed relatively high similarity in composition of seedlings, 50 m shrub and herbaceous transects, shrub belts and herbaceous frames between burn and control plots in 1999 and 2000 (Table 3). They indicated little to no overall effect in these populations from the prescribed burn. Authors believe results would have indicated greater changes in composition had the burns been more severe.

In the seedlings class, loblolly pine, white oak and Southern red oak (*Quercus falcata* Michx.) were common. Sassafras (*Sassafras albidum* (Nutt.) Nees) was absent from the burn plots in 1999, while it was present to either a moderate or heavy degree in 2000.

Table 3. Morisita's similarity index results for plot comparisons at Mission Tejas, Tyler and Village Creek State Parks pre- (1999) and post-burn (2000).

Park	Plots compared	Seedlings	50 m shrub and herbaceous transects	Shrub belts	Herbaceous frames
Mission Tejas	Pre-bum: bum vs. control	0.93	0.61	0.76	0.69
	Post-bum: bum vs. control	0.89	0.94	0.84	0.85
	Bum plots: pre- vs. post-bum	1.00	0.95	0.88	0.99
	Controls: pre- vs. post-bum	0.97	0.88	0.88	1.20
Tyler	Pre-bum: bum vs. control	1.02	0.76	0.94	0.85
	Post-bum: bum vs. control	0.92	0.99	0.99	0.95
	Bum plots: pre- vs. post-bum	0.99	0.85	0.96	0.92
	Controls: pre- vs. post-bum	1.02	0.98	0.90	0.96
Village Creek	Pre-bum: bum vs. control	1.00	1.01	0.86	0.00
	Post-bum: bum vs. control	1.00	0.00	0.60	0.00
	Bum plots: pre- vs. post-bum	1.00	0.80	1.02	0.43
	Controls: pre- vs. post-bum	1.01	0.00	0.41	0.00

For the 50 m shrub and herbaceous transect, litter was more commonly intersected than all plant species combined. In the previously burned plot, the transect was dominated by a heavy ground cover of poison ivy, with little room for anything else. Smilax *(Smilax* sp.), Virginia creeper *(Pwthenocissus quinquefolia* (L.) Planch.), poison ivy, muscadine grape *(Vitis rotundifolia* Michx.) and partridge-berry *(Mitchella repens* L.) were commonly intersected in the other plots.

The 0.5 m wide shrub belts in all plots at Mission Tejas were dominated by poison ivy, smilax and Virginia creeper, with moderate amounts of muscadine grape and American beautyberry. In the herbaceous classification, the only obvious change from 1999 to 2000 was the heavy presence of goldenrod *(Solidago* sp.) in two of the burn plots in 2000. Goldenrod is a common invader species after disturbance, and was not recorded at all in 1999.

This burn was part of the fuel reduction phase described in the burn plan (Robinson & Blair 1997). Killing or weakening under-story shrubs and pine saplings was one goal of the fuel reduction phase. Results indicated no significant changes in overstory, sapling, seedling, shrub or herbaceous populations.

Tyler State Park.-The overstory of plots at Tyler State Park was characterized by shortleaf pine and post oak (*Quercus stellata* Wangenh.). There were no significant changes in dead standing overstory trees from 1999 to 2000.

When graphed in DCA, two plots were commonly placed on the right of the rest of the group. Axis 1 represented soil moisture, with decreasing soil moisture to the right of the graph. These two plots were higher in elevation and would have lower soil moisture than the others.

T-tests indicated a significant increase in percent of dead saplings in 2000 in the burn plots ($t = 3.004$, $P = 0.003$). In 1999, there were 7.9 percent dead saplings while there were 18.5 percent in 2000. The control plots indicated the opposite trend, although it was not significant statistically. Thus the increase in the burn plots was evidently due to the burn. Saplings were already suffering drought stress and the additional stress of the burn exterminated weaker individuals. Further t-tests indicated no significant differences in dbh or height class of saplings from 1999 to 2000, indicating that combined stresses affected saplings of all diameters and heights evenly.

Morisita's similarity index illustrated very high similarity between seedlings, 50 m shrub and herbaceous transects, shrub belts and herbaceous frames, from 1999 to 2000, even between burn and control plots (Table 3). In the seedlings class, sweetgum and sassafras were most common, followed by Southern red oak, winged elm (*Ulmus alata* Michx.), red maple, flowering dogwood and American elm. Litter was most often recorded in the 50 m shrub and herbaceous transects. In 2000, twinspan separated plots based on the presence of bare ground. No bare ground was recorded in 1999. The presence of it in 2000 could have been a result of the prescribed burn removing the 0 horizon.

There were some changes in shrub belt data from 1999 to 2000 in Tyler State Park. Muscadine grape, poison ivy and smilax were common. American beautyberry was absent in 1999, while there was a heavy presence of it in one plot in 2000 that had burned very hot, as evidenced by char height after the burn. Virginia creeper, which was heavily present in that plot in 1999, was absent in 2000. Longleaf uniola was common in the herbaceous frames.

The 10.6 percent increase in dead saplings appears to be the only significant difference in vegetation. The burn plan (Sparks 1999a) called for increasing herbaceous species, reducing brush species and enhancing species diversity and richness. None of these objectives were reached. The burn was not hot enough to accomplish these goals.

Village Creek State Park. -The overstory of Village Creek was characterized by longleaf pine, southern red oak, and sweetgum. Plots closest to the creek were separated from the others in twinspan because they contained river birch, commonly found in wet soils and stream-banks, and Southern magnolia (***Magnolia*** *grandiflora* L.), also common in moist valleys (Little 1980). They also contained lesser amounts of Southern red oak than did other plots, which is more commonly found in dry, sandy loams (Little 1980). When graphed, DCA Axis 1 represented increasing soil moisture in both years in most vegetation classes. T-tests indicated no significant changes in standing dead overstory trees.

In saplings, yaupon and redbay were dominant. T-tests indicated a significant increase in the number of dead saplings in the burn plots from 1999 to 2000, 12.6 to 19.6 percent, respectively (t = 2.286, P = 0.023). There was only a slight increase in the control plots, from 12.8 to 13.9 percent. This illustrated a cumulative effect within the burn plots of the drought and the burn combined. There were no significant differences in dbh and height class between 1999 and 2000, illustrating that combined impacts of fire and drought affected all sizes evenly.

Chinese tallowtree was becoming increasingly common in the sapling and seedling stages at Village Creek. It is a native species of China, which has been widely planted as an ornamental in the U.S., because of its vivid fall colors. Seedlings less than one foot tall were omnipresent in areas that were typically wet, but dry due to drought. Chinese tallowtree is hardy, common in sandy soils along streams and grows quickly into thickets (Little 1980). It has the potential to overtake natural vegetation in many areas of the park if left unmanaged.

Morisita's similarity index reflected nearly exact similarities in seedling composition between all control and burn plots in both years (Table 3). The burn appeared to have no effect on composition of seedlings. This was not surprising considering the wet condition of the fuels during the burn.

On the shrub and herbaceous transects, litter dominated intercepts on all plots. There were more species of vegetation, and vegetation occurred more often in 1999 than 2000. Although a burn could cause a reduction in shrub species, even herbaceous species, such as little bluestem and a carex sedge (*Carex joorii* Bailey) were also reduced. This is more indicative of drought effects than those of prescribed burning.

Morisita's similarity index indicated a high degree of similarity between burn and control plots in 1999 (Table 3). However, in 2000, every hit along transects within control plots contacted no vegetation, only litter. This resulted in 0.00 similarity between burns and controls in 2000, and controls in 1999 and 2000. The lack of brush and herbaceous vegetation in the control plots was due to the sustained drought. Village Creek is the northern boundary of the park. The creek often floods in the winter and spring and cypress swamps are present near both the control and the burn units. Because of the drought, the yearly flooding had not occurred in 1999 or 2000; the swamps were dry, and vegetation severely affected.

There were also decreases in the total number of shrub belt species and the numbers recorded within species from 1999 to 2000. The drought appeared to play an important factor from the first year to the next. Some species increased in certain plots while decreasing in other plots, with other species exhibiting opposite responses in those same plots. This is indicative of too few resources. The species with the firmer hold on an area won out.

Morisita's index also indicated a cumulative effect of the drought and the burn in Village Creek's shrub belt composition (Table 3). Oddly, the highest rating (1.02) was received by the similarity in the burn plots between 1999 and 2000, indicating no effect on composition by the burn.

The effect of prolonged drought was also evident in the herbaceous frames. In both years, the majority of herbaceous frames were empty in all plots. Morisita's similarity index resulted in all comparisons receiving either 0.00 or a low rating (Table 3). This was due to the total lack of herbaceous vegetation in many of the frames in 2000.

At Village Creek the only significant effect of the burn on vegetation was in the percent of dead saplings. The increase, seven percent, in the burn plots was six percent greater than in the control plots. The objectives of encouraging longleaf seedlings, herbaceous species, and increasing species richness and diversity were not met.

CONCLUSIONS

Compared to forests with long-interval, high-severity fire regimes, characterized by stand replacing fires, forests with low- to moderate-severity regimes, characterized by low-intensity surface fires may experience greater adverse effects from high intensity wildfires because they are not adapted to them. Generally, these forests adapted to low-intensity surface fires are more adversely affected by fire suppression and other human influences following European settlement. Active fire seasons occur at more frequent intervals than in long-interval types, due to longer fire seasons, higher average temperatures, and exposure to more potential ignitions during a given fire season. They have missed more fire cycles than longer interval fire regimes, and are generally in greater need of wildfire hazard reduction and restoration of ecological integrity. Wildfires in these areas not only cause more detrimental ecological effects, but they pose great risks to firefighters and property.

It is anticipated with most prescribed burning programs, that the resulting post-fire landscape will have significantly reduced fuel loads and reduced risks of detrimental wildfires. If the post-fire landscapes are also attractive to those who influence policy, positive social benefits can be anticipated as well.

The primary goal of each of these burns was to reintroduce or establish prescribed burning in these parks to further this mission. That objective was met. Park staffs were introduced to the duties, dangers and special considerations necessary with conducting prescribed burns. Each time they are performed by park staff, burns should become less stressful and more efficient.

This short-term project has determined that future burns must be more intense to meet the fuel loads and vegetation goals outlined in the burn plans. This will require a great deal of cooperation and preparedness from park staff. The window of opportunity to conduct a burn with the desired outcomes may be quite small in any given year. Fuel moisture, wind direction and speed, ambient temperature and capable staff availability must all be ideal to conduct a burn. Once the natural resources coordinator (NRC) has identified an area to be burned it is the responsibility of the park staff to prepare and maintain it in a ready condition.

Initially, dormant season burns should be conducted every two years to reduce fuel loads sufficiently to initiate early to late spring burns. This will require at least two more cool season burns of greater intensity than the burns presently studied. Spring burns occurring every three years will establish a vegetation restoration phase. After a diverse herbaceous layer and open understory have been established, a maintenance phase of burning every five to eight years, depending on desired vegetation, can begin (DellaSala & Frost 2001; Manley et al. 2001).

In years with inadequate prescribed fire windows due to extreme drought or flooding, prescribed burning should not be undertaken. It is too expensive and inefficient to extract employees from their normal duties, and use expensive tools, trucks and ATVs to accomplish so little ecologically. However, TPWD personnel must be willing to take risks based on the best available knowledge. Increasingly, scientific information points to the necessity of fire in maintaining sustainable, healthy forests in the Southeast. Being too cautious could be just as detrimental to the forest as an escaped prescribed fire. The risks of damage from wildfire, disease, insects and overcrowding are increased when prescribed fire is put off another year in hopes of better burning conditions. Fire exclusion will ultimately result in a shift from a nonlethal understory fire regime to a stand-replacement regime accompanied by changes in composition and diversity.

In Texas, county judges are responsible for issuing burn bans, even those with little ecological experience on which to rely. Ideally, a relationship should be fostered between the NRC and county judges issuing the bans. Judges are accustomed to making decisions based on facts and the good of the whole, rather than emotion. They should be capable of understanding the importance of fire on the landscape and the precautions taken to keep prescribed burns contained. These parks, particularly Village Creek, would have burned naturally during very dry periods. To be forced to adhere to burn bans during these times greatly reduces the restorative powers of prescribed burning. The judges have the authority to allow TPWD to burn for ecological reasons during a burn ban.

In this instance, had TPWD not been bound by the burn bans, burns could have been conducted when fuels were more dry. The failure to reach the objective of reducing fuels in the parks was a direct result of waiting until after a rain event occurred to burn.

Long-term interdisciplinary research projects are necessary to quantify the ecological effects, and economic and social trade-offs of prescribed burning. Only through long-term research may it be determined which natural fire functions can be emulated with prescribed burning, which are irreplaceable, and the implications for management.

ACKNOWLEDGMENTS

The authors wish to thank Jeff Sparks of Texas Parks and Wildlife Department; student workers Stephanie Price, Kelly Scott and Terry Hanzak for data collection, and Drs. Michael H. Legg, Kenneth W. Farrish and Ray L. Darville from Stephen F. Austin State University. The authors also appreciate the constructive comments of two anonymous reviewers.

LITERATURE CITED

Brown, J. K., R. D. Oberheau & C. M. Johnston. 1982. Handbook for Inventorying Surface Fuels and Biomass in the Interior West. USDA For. Serv. Gen. Tech. Rep. INT-129. Intm. For. and Range Exp. Stn., Ogden, Utah, 18 pp.

DellaSala, D. A. & E. Frost. 2001. An Ecologically Based Strategy for Fire and Fuels Management in National Forest Roadless Areas. Fire Mgmt. Today, 61(2): 12-21.

Jurney, D. 2000. Fire History of the West Gulf Coastal Plain. Presented at the Third Longleaf Alliance Regional Conference, October 16, 2000, Alexandria, Louisiana.

Little, E. 1980. The Audubon Society Field Guide to North American Trees: Eastern Region. New York: Alfred A. Knopf, 639 pp.

Manley, J., M. Keifer, N. Stephenson & W. Kaage. 2001. Restoring Fire to Wilderness: Sequoia and Kings Canyon National Parks. Fire Mgmt. Today, 61(2):24-28.

McCune, B. & M. J. Mefford. 1999. PC-ORD. Multivariate Analysis of Ecological Data. Version 4. Gleneden Beach, Oregon: MJM Software Design.

Morisita, M. 1959. Measuring of Interspecific Association and Similarity between Communities. Memoirs of the Faculty of Science Kyushu University Series E3:65-80.

Mutch, R. W. 1994. Fighting Fire with Prescribed Fire: A Return to Ecosystem Health. J. of Forestry, 92(11):31-33.

Reeves, H. C. & D. Corbin. 1985. Fire and the Big Thicket. Texas Nat. Hist., 1(2):23-26.

Robinson, C. & K. Blair. 1997. Fire Management Plan: Mission Tejas State Historical Park. Texas Parks and Wildlife Department, 14 pp.

SPSS Inc. 1999. SPSS Base 10.0. Chicago, Illinois: SPSS Inc.

Sparks, J. C. 1999a. Fire Management Plan: Tyler State Park. Texas Parks and Wildlife Department, 22 pp.

Sparks, J. C. 1999b. Prescribed Fire Bum Plan: Village Creek State Park. Texas Parks and Wildlife Department, 13 pp.

Texas Parks and Wildlife. 2000a. Parks and Historic Sites: Mission Tejas State Historical Park. Last updated November 13, 2000. http://www.tpwd.state.tx.us/park/mission/mission.htm (12/18/00).

Texas Parks and Wildlife. 2000b. Parks and Historic Sites: Tyler State Park. Last updated November 14, 2000. http://www.tpwd.state.tx.us/park/tyler/tyler.htm (12/18/00).

Texas Parks and Wildlife. 2000c. Parks and Historic Sites: Village Creek State Park. Last updated November 14, 2000. http://www.tpwd.state.tx.us/park/village/village.htm (12/18/00).

Western Region Prescribed and Natural Fire Monitoring Task Force. 1992. National Park Service Western Region Fire Monitoring Handbook. USDOI National Park Service, San Francisco, California, 261 pp.

SR at: srideout@fs.fed.us

Developing an integrated system for mechanical reduction of fuel loads at the wildland/urban interface in the southern United States

John Stanturf[1], Robert Rummer[1], Michael Wimberly[2], Timothy Rials[3], Philip Araman[1], Rodney Busby[4], James Granskog[1], Les Groom[1]

[1]Project Leader, USDA Forest Service, Southern Research Station, USA, [2]Assistant Professor Landscape Ecology, Warnell School of Forest Resources, University of Georgia, USA, [3]Director, Tennessee Wood Products Centre, University of Tennessee, USA, [4]Research Economist, USDA Forest Service, Southern Research Station, USA

Summary

Prescribed fire is used routinely in the southern United States to reduce fuel loading and decrease the risk of catastrophic wildfires, improve forest health, and manage threatened and endangered species. With rapid human population growth, southern forests have become fragmented by an extensive road network and intertwined with urban uses in a wildland-urban interface (WUI) pattern. It is practically impossible to use prescribed fire in the more urbanized portions of the interface. Nevertheless, fuel reduction treatments still are needed in fire-dominated "urban woodlands." Alternatives to prescribed burning may involve mechanical reduction of current fuel loads and maintenance of low-risk understory through herbicides. Techniques are needed that can effectively reduce fuel loads through mechanical means, and are acceptable to homeowners. Additionally, utilization scenarios need to be identified for this class of raw material to make removal economically attractive to operators. An integrated system is being developed that will manage fuel loads in urban woodlands through mechanical means.

Keywords: *Vegetation management, engineering systems, landscape ecology, prescribed fire.*

Introduction

Prescribed fire is used routinely in the South to reduce fuel loads and decrease the risk of catastrophic wildfires; to improve forest health; and to manage threatened and endangered species. The ability to use prescribed fire is problematic in urbanizing areas of the South, the so-called wildland-urban interface (WUI). Nevertheless, fuels must be managed even in urban woodlands. Mechanical alternatives to prescribed fire have been proposed to reduce current fuel loads that have built up during the last 50 years of aggressive fire suppression. Herbicides or continued mechanical methods will be needed to maintain understory species of low fire risk. Methods must be acceptable to home-owners, as well as cost-effective. This paper provides an early report of efforts to develop an integrated system of managing fuel loads in the WUI environment.

Characteristics of the Interface

Demographic changes in the South affect natural resources and the attitudes of southerners to traditional management practices such as prescribed fire (Cordell *et al.* 1998). The WUI, where homes or other structures are adjacent to, or intermixed with forests is a particularly vexing locale for natural resource managers (Macie and Hermansen 2002). More people are living at the interface and the transportation system is expanding, becoming denser and more pervasive. In most of the South, this is an area of fire-adapted natural vegetation. Critical challenges for managers include wildfire prevention, suppression, and mitigation. Increasingly, one of the most effective tools in the manager's kit, fuel reduction by frequent understory burning, is off-limits because of safety and liability risks (Achtemeier *et al.* 1998, Wade and Brenner 1995) or public dislike for inconvenience of smoke (Macie and Hermansen 2002).

The traditional idea of the wildland urban interface is an area of urban sprawl where new housing developments abut public or private wildland. A less obvious form is the isolated interface where scattered, remote structures are dispersed in wildland. Typically these are second home or summer recreation structures surrounded by forest vegetation. The wildland island is a park or forest stand within an urban area. Between these extremes is the intermix zone of areas undergoing a transition from natural resource uses such as forestry or agriculture to urban uses. These areas may have been bypassed by leapfrog urban development. Each type of WUI is dynamic; parcel size generally decreases, further fragmenting forest cover; road and population densities generally increase, accompanied by changing demographic profiles and cultural values (Cordell *et al.* 1998). The vegetation communities types, stand structures, fuel types and loads vary as well by physiographic province, from the coast to the mountains. There is no single parameter, or simpie set of parameters, that adequately describe the WUI environment.

Fuel Reduction Methods

Forest operations appropriate for WUI conditions applications must be matched to terrain and stand conditions, the unique constraints of operating in the WUI, the product specifications of any extracted materials, and the prescription requirements of the treatment. Conventional mechanical reducedon equipment is designed to operate effectively on large areas so high speed and maximum cutting width are common design goals. Operations for the WUI, on the other hand, should be lightweight to minimize soil impacts and road transportation problems. Cutting width and speed may not be as important as minimizing thrown debris and operating in tight quarters near structures and the public.

Operations to extract material must be properly adapted for WUI applications. Conventional forest operations face significantly increasing costs as tract size drops below 10 ha (Greene and others 1997). This is primarily due to the increasing overhead of move-in costs and delay time associated with large capital-intensive equipment. In the WUI, operations that involve a single machine performing multiple functions will have lower move-in costs. Smaller equipment may also be advantageous if multiple machines can be moved on a single transport trailer.

The equipment configuration must also be tiered to the product and processing possibilities. Biomass material that has no product value should be treated (mulched) in the stand to minimize costs. Larger diameter material may have value as pulpwood, fuel chips, or even sawlogs. This material may be processed to appropriate dimensions, extracted from the forest and transported to mills. In dense, overstocked stands resulting from fire suppression, reducing fuel loads through biomass thinning may allow use of prescribed fire (Wade *et al.* 1998). In such cases, combining a small chipper with cut-to-length harvesting systems may be feasible (Bolding and Lanford 2001). A complete fuel reduction treatment in the WUI will thus require an integrated system of several machines to achieve stand management goals while minimizing costs and maximizing fibre recovery and utilization.

Markets

Viable markets and economical processing would provide outlets for small-diameter timber in our forests and in the WUI. Forests currently provide a multitude of wood products with many produced from small diameter timber (Hansen *et al.* 2001). Among these is dimension lumber and construction wood products that include engineered wood products. Also a variety of specialty products targeted at niche markets are currently produced. Expanding production of engineered wood products could utilize larger amounts of small-diameter timber and several under-utilised species. Resulting removals of small-diameter timber would contribute significantly to a reduction in fuel loads and a lessening of the potential for catastrophic fire. Available local markets will be the key to developing effective fuel reduction methods to being fuel loads back to manageable levels.

References

Achtemeier, G.L., Jackson, W., Hawkins, B., Wade, D.D., and McMahon, C. 1998. The smoke dilemma: A head-on collision! In Wadsworth, K.G., editor, Transactions of the 63rd North American Wildlife and Natural Resources Conference, held 20-24 March 1998, Orlando, FL. Wildlife Management Institute, Washington, DC: 415-421.

Bolding, M.C. and Lanford, B.L. 2001. Forest fuel reduction through energy wood production using a small chipper/CTL harvesting system. Proceedings of 24th Annual Meeting Council on Forest Engineering, 15-19 July 2001, Snowshoe, West Virginia. Council on Forest Engineering, Corvallis, OR; CD-ROM.

Cordell, H.K., Bliss, J.C., Johnson, C.Y., and Fly, M. 1998. Voices from Southern forests. In Wadsworth, K.G., editor, Transactions of the 63rd North American

Wildlife and Natural Resources Conference, held 20-24 March 1998, Orlando, FL. Wildlife Management Institute, Washington, DC: 332-347.

Greene, W. Dale; Harris, Thomas G.; DeForest, Christopher E.; Wang, Jingxin. 1997. Harvesting cost implications of changes in the size of timber sales in Georgia. Southern Journal of Applied Forestry. 21(4): 193-198.

Hansen, B., Araman, P., West, C., and Schuler, A. 2001. Hardwood timber markets-a focus on small diameter. World Forestry Directions, Sterling Publications Ltd. London and Ligna Hannover. 2 pp.

Macie, E.A. and Hermansen, L.A., editors. 2002. Human influences on forest ecosystems—the Southern wildland-urban interface assessment. USDA Forest Service Southern Research Station General Technical Report SRS-55. Asheville, NC: 160 p.

Wade, D.D. and Brenner, J. 1995. Florida's solution to liability issues. In Weise, D.R. and Martin, R.E., technical coordinators, Proceedings of the Biswell Symposium: fire issues and solutions in urban interface and wildland ecosystems. USDA Forest Service, Pacific Southwest Research Station General Technical Report PSW-158. Berkeley, CA: 131-138.

Wade, D.D., Custer, G., Thorsen, J., Kaskey, P., Kush, J., Twomey, B., and Voltolina, D. 1998. Reintroduction of fire into fire-dependent ecosystems: Some southern examples. In Pruden, T.L. and Brennan, L.A., editors, Fire in ecosystem management: shifting the paradigm from suppression to prescription. Tall Timbers Ecology Conference Proceedings No. 20. Tall Timbers Research Station, Tallahassee, FL: 94-98.

Windell, K. and Bradshaw, S. 2000. Understory biomass reduction methods and equipment. USDA Forest Service, Technology & Development Program 0051-2828-MTDC. Missoula, MT. [partial document summarizing the full version, Understory Biomass Reduction Methods and Equipment Catalogue 0051-2826-MTDC]

Profile

John Stanturf is Project Leader, Disturbance and Management of Southern Ecosystems unit of the USDA Forest Service, Athens, Georgia. The unit is the primary research group studying fire in the southern United States. Stanturf is a forest soil scientist (PhD Cornell University). His personal research focuses on ecosystem restoration. He is Working Party Chair of the IUFRO WP 1.17.02, Restoration of Boreal and Temperate Forests and Working Group Deputy, 1.17.00, Restoration of Degraded Sites. Stanturf is a member of the IUCN Commission on Ecosystem Management and member of the Silviculture Working Group of the North American Forestry Commission (FAO).

John A. Stanturf
320 Green Street
Athens, GA 30602
USA
001-706-559-4316
001-706-202-8066 (work)
jstanturf@fs.fed.us

ARBETSRAPPORT

FRÅN SKOGFORSK NR 539 MAJ 2003

2nd Forest Engineering Conference

12—15 May 2003, Växjö, Sweden

Proceedings

Posters:

TECHNIQUE AND METHODS

Maria Iwarsson Wide & Ingegerd Hallberg (Eds.)

SKOGFORSK

Uppsala Science park. SE-751 83 UPPSALA, Sweden Ph. +46 18 18 85 00 I Fax. +46 18 86 00
skogforsk@skogforsk.se • http://www.skogforsk.se

FOREST RESOURCES ASSOCIATION INC.
600 JEFFERSON PLAZA, SUITE 350
ROCKVILLE, MARYLAND 20852
PHONE: 301/838-9385 FAX: 301/838-9481

TECHNICAL RELEASE
O5-R-16

FUEL-REDUCTION TREATMENTS WITH A GYROTRAC GT-25

Fire: forest protection *June 2005*
www.forestresources.org/members/serpub/05-r-16.html

INTRODUCTION: Land managers in urban areas are turning to mulching equipment as a tool for managing their timberlands. Prescribed burning to reduce fire risk may not be an option, due to smoke management concerns and the level of current fuel loading.

On a wet, rainy day in December, 2004, the U.S. Forest Service, Southern Research Station, Forest Operations Research Unit held a demonstration of the GyroTrac GT-25 in Auburn, Alabama. Dick Martin, Alabama Agriculture Experiment Station Forester, offered a high risk area of the Auburn University campus for demonstrating this mulching equipment. The selected site is a popular tailgating location near Jordan-Hare Stadium and directly adjacent to buildings and a heavily traveled roadway; for those reasons, prescribed burning is not an option. Jon Flournoy (Sales Manager) and Steve Shavers (Sales Representative) of GyroTrac delivered and operated the GT-25 model used for the demonstration.

Fig. 1: *The GyroTrac GT-25 mulches vegetation in an urban area to reduce the risk of wildfire.*

Many types of mulching machines are commercially available today. It is important for land managers to have information about these machines to make informed decisions when matching machines to specific applications and site conditions.

Fig. 2: *Mulching equipment is effective in removing unwanted vegetation like this.*

GENERAL FEATURES: The GyroTrac GT-25 is a purpose-built machine. GyroTrac holds the patents on the track system and on the cutting head. The heated and cooled pressurized cab has an air filtering system for operator comfort.

The 8.5-foot wide cutting head mulches a 7.75-foot swath. There are 36 individual fixed teeth. These self-sharpening planer-style teeth not only grind material but can till the mulch into the ground. A bar attached to the cutting head pushes stems over while severing them at the base. The cutting head can be raised or lowered as needed. This machine is easily capable of severing and mulching 10-inch dbh trees.

The flexible suspension allows the tracks to maintain greater ground contact than conventional tracked systems. This rubber-track with metal cleat system is designed to allow this machine to work on wet days and in a variety of environments. The 21,500-pound machine has nine feet of track in contact with the ground, which equates to approximately 3.6 psi. Each track is approximately 28 inches wide.

APPLICATION: GyroTrac machines have been used for a variety of land management treatments including: controlling invasive species, improving wildlife habitat, clearing salvage areas, pre-commercial thinning, controlling insect infestations, and clearing fire lines for wildlife suppression and prescribed burning. A global positioning system (GPS) can be mounted in this equipment to guide the operator to specified treatment areas.

Fig. 3: *Post-treatment appearance.*

SPECIFICATIONS AND COSTS: The GyroTrac GT-25 has a 225-horsepower six-cylinder Cummins Turbo Diesel engine. Four hydraulic pumps provide 4,800 psi with a hydraulic flow rate of 38 gallons per minute.

The list price of the GyroTrac GT-25 as demonstrated is $350,000[1]. Individual teeth can be replaced as they break or wear. A set of replacement teeth currently costs $1,600[1].

Fig. 4: *GyroTrac GT-25 tooth design.*

COMMENTS: The newest version of this model is eight feet wide to avoid wide load permits in some states. Smaller and larger models are available, with a range of engine sizes and a variety of head/teeth designs. Additional information regarding this and other models is available from the manufacturer's internet site at www.gyrotrac.net or by phone at 866/800-3900.

Fuel-reduction through mechanical treatments is an area of current interest for the Forest Operations Research Unit. Further information concerning this cutting system, or other mechanical treatments, may be obtained from the authors.

Dana Mitchell, Research Engineer
Jason Thompson, Support Engineer
USDA Forest Service
Southern Research Station
520 Devall Drive
Auburn, Alabama 36849-5418
334/826-8700

Reviewed by:
Jason Cutshall
Southcentral Technical Division Forester

[1] Prices subject to change without notice.

QUANTIFYING AND RANKING THE FLAMMABILITY OF ORNAMENTAL SHRUBS IN THE SOUTHERN UNITED STATES

Alan J. Long and Anna Behm
School of Forest Resources and Conservation (PO Box 110410), University of Florida, Gainesville, FL 32611, USA. Telephone: +1 352 846 0891; fax: +1 352 846 1277

Wayne C. Zipperer and Annie Hermansen
Southern Center for Wildland-Urban Interface Research and Information, P.O. Box 110806, USDA Forest Service, Gainesville, FL 32601, USA.

Alexander Maranghides and William Mell
National Institute of Standards and Technology, Gaithersburg, MD 20899, USA.

INTRODUCTION

Wildfire preparedness programs focus on education and provide assistance with community design, home construction, and landscape design. Wildland-Urban Interface (WUI) residents, nursery employees, and landscape architects often request lists containing species that would be appropriate for placement in firewise landscaping. Existing lists were created from personal experience or based on lists originating in the western United States. These lists, when applied to southern landscape designs, have inconsistencies.

Even with extensive research, there is still no standard method of ranking plant flammability. Although it is possible to measure the individual plant characteristics that influence flammability, it is not known how those individual characteristics affect overall plant flammability (Behm et al. 2004). A recent study found that the flammability of entire plants is most influenced by foliar moisture content and the quantity of foliar biomass (Etlinger and Beall 2004). To compare species, it is important to reduce the impact of environmental variables such as wind and relative humidity; and to accurately and precisely measure the flammability of entire shrubs. These criteria were met by performing all tests using the large-scale calorimetry equipment at the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) in Gaithersburg, Maryland. The research objective was to rank landscape shrub species from the South by their flammability.

METHODOLOGY

<u>Species selection</u>: Species were selected from a survey sent to WUI fire professionals in the South to identify species in their area that are highly flammable, less flammable, and species with unknown flammability. From these surveys, we selected 34 species from all three categories and based on the following criteria: shrub, non-invasive, and desirable plant characteristics.

Measuring Flammability: The major components of flammability are: ignitability, sustainability, combustibility, and consumability (Martin et al. 1994). Ignitability was quantified based on time to independent ignition. The ignition source was a u-shaped gas burner. Sustainability included the time interval after independent ignition to the end of flaming combustion. Tests were videotaped to validate the measurement of time intervals.

Combustibility was measured in multiple ways. The first measurement was peak heat release rate (Peak HRR). Total energy released was the second measurement. Maximum flame height was also recorded as a measure of combustibility. Consumability, or the amount of the plant that is burned in fire, was measured with a spatial comparison of initial canopy volume to remaining canopy volume after combustion. Plants were placed in front of a placard with a defined grid and the change in cover was estimated by comparing before and after images on the placard. Digital pictures were taken in two directions before and after the fire test.

Plant measurements: Variables that may influence the flammability included height, average width, foliar moisture content, and foliar energy content. Overall height and height to the lowest branch were measured prior to ignition. Crown width at half the plant height was measured in two directions. A sample of leaves was collected from the plant prior to ignition and immediately weighed. Samples were returned to the University of Florida where dried-weights were obtained. Moisture content was reported in % moisture content by dry weight. The dried leaf sample used to test the moisture content of leaves was also used in an energy content analysis. Standard isoperibol oxygen combustion calorimetry (Parr® Model 1261 Calorimeter) was conducted at the University of Florida.

Statistical analysis: Principle component and cluster analysis were utilized to determine comprehensive differences in flammability among the southern shrub species tested. The principle component analysis identified the importance of dependent variables for differentiating among species. The cluster analysis of all dependent variables was used to group species into categories of flammability.

RESULTS AND DISCUSSION

With a cluster analysis utilizing all quantified flammability characteristics (PHRR, total energy, mass loss, plant density loss, time to ignition, maximum flame height, temperatures, and heat fluxes), three clusters or rankings of flammability were identified. Twenty-two species were ranked as low flammability, eight species as moderate flammability, and four species as high flammability- *Ilex glabra*, *Ilex vomitoria*, *Juniperus chinensis*, and *Kalmia latifolia* (Table 1). These four species should not be planted close to structures. Species ranked as moderate flammability could become highly flammable under drought conditions. Similarly, these species should not be planted near structures. The study did identify 22 species that can be used in firewise planning.

LITERATURE CITED

Behm, A. L., M. L. Duryea, A. J. Long, and W. C. Zipperer. 2004. Flammability of native understory species in pine flatwood and hardwood hammock ecosystems and implications for the wildland-urban interface. International Journal of Wildland Fire **13**:355-365.

Etlinger, M. G., and F. C. Beall. 2004. Development of a laboratory protocol for fire performance of landscape plants. International Journal of Wildland Fires **13**:479-488.

Martin, R. E., D. A. Gordon, M. I. Gutterrez, D. S. Lee, D. M. Molina, R. A. Schroeder, D. B. Sapsis, S. L. Stephens, and M. Chambers. 1994. Assessing the flammability of domestic and wildland vegetation. Pages 130-137 *in* Proceedings of the 12th Conference on Fire and Forest Meteorology. Society of American Foresters.

Table 1. Flammability ranking for 34 commonly used horticultural plants in the South by their flammability ranking—high, moderate, and low—tested under controlled environmental conditions.

Common Name	Scientific Name	Cultivar Name	Flammability Rank
Glossy abelia	*Abelia* x *grandiflora* (André) Rehd.		Moderate
Pipestem	*Agarista populifolia* (Lam.) Judd		Moderate
Azalea	*Azalea obtusum* (Lindl.) Planch.	'Hershey red'	Moderate
Butterfly bush	*Buddleia davidii* (Franch.)	'Royal red'	Low
Boxwood	*Buxus microphylla* Siebold & Zucc. var. *koreana* Nakai	'Wintergreen'	Moderate
Beautyberry	*Callicarpa dichotoma* (Lour.) C. Koch	'Profusion'	Low
Camellia	*Camellia japonica* L.		Low
Summer-sweet; sweet pepperbush	*Clethra alnifolia* L.		Low
Leyland cypress	x *Cupressocyparis leylandii* (A. B. Jacks. & Dallim.)		Moderate
Klein's forsythia	*Forsythia* x *intermedia* Zab.		Low
Cape jasmine	*Gardenia jasminoides* Ellis	'August beauty'	Low
Bigleaf hydrangea; French hydrangea	*Hydrangea macrophylla* (Thunb.) Ser.	'Nikko'	Low
Oakleaf Hydrangea	*Hydrangea quercifolia* Bartr.		Low
Foster holly	*Ilex* x *attenuata* Ashe	'Fosteri'	Low
Gallberry	*Ilex glabra* L.	'Compacta'	High
Blue holly	*Ilex* x *meservea* S. Y. Hu	'Mesdob'	Moderate
Winterberry	*Ilex verticillata* (L.) A. Gray	'Berry nice'	Low
Dwarf yaupon	*Ilex vomitoria* Ait.	'Schellings dwarf'	High
Anisetree	*Illicium floridanum* Ellis		Low
Ashe juniper; Ozark white cedar	*Juniperus ashei* Buchh.		Moderate
Chinese juniper	*Juniperus chinensis* L.	'Pfitzerana'	High
Mountain laurel; calico bush	*Kalmia latifolia* L.	'Olympic fire'	High
Bayberry; candleberry	*Myrica pennsylvanica* Loisel.		Low
Oleander	*Nerium oleander* L.	'Calypso'	Low
Pittosporum	*Pittosporum tobira* (Thunb.) Ait.	'Compacta'	Low
Potentilla; shrubby cinquefoil; golden hardhack	*Potentilla fruiticosa* L.	'Gold star'	Low
Scarlet firethorn	*Pyracantha coccinea* M. J. Roem.	'Mohave'	Low
Rhododendron	*Rhododendron* L. x *chionoides*	'Chionoides'	Moderate
Rosebay; great laurel	*Rhododendron maximum* L.		Low
Arrowwood	*Viburnum dentatum* L.	'Chicago luster'	Low
Walter's viburnum	*Viburnum obovatum* Walt.		Low
Weigela	*Weigela florida* (Bunge) A. DC.	'Wine and roses'	Low
Adam's needle	*Yucca filamentosa* L.		Low
Coontie	*Zamia pumila* L.		Low

For more information:

http://edis.ifas.ufl.edu
http://edis.ifas.ufl.edu/TOPIC_SERIES_Fire_in_the_Wildland_Urban_Interface
www.interfacesouth.org

THE WILDLAND-URBAN INTERFACE IN U.S. METROPOLITAN AREAS

Susan I. Stewart, *USDA Forest Service, Evanston, IL*

Volker C. Radeloff, *Department of Forest Ecology and Management, University of Wisconsin, Madison, WI*

Roger Hammer, *Department of Rural Sociology, University of Wisconsin, Madison, WI*

ABSTRACT: Wildland urban interface (WUI) issues are significant for urban foresters. An analysis of 12 metropolitan areas shows that the WUI is concentrated in these metro areas relative to the rest of their respective states.

Introduction

The interface between wildland vegetation and human settlements holds unique challenges for resource management (Macie and Hermansen 2002). The significance of the wildland-urban interface (WUI) has grown in recent years because the WUI itself has grown. Widespread, rapid housing growth during the 1970s and 1990s, particularly in rural areas and on the fringes of urban areas, has created more interface areas (Heimlich and Anderson 2002). This paper presents a spatial analysis of the WUI surrounding urban areas in 12 selected metropolitan areas in the U.S.

Policy makers and fire professionals recognize that the WUI is an area where wildland fire puts homes and people at risk (Cohen 1991). The National Fire Plan enacted in 2000 directs resources to communities in the WUI (USDA and USDI 2001). While the risk of fire is currently the most high-profile WUI issue, there are other issues of equal or greater significance to resource managers such as wildlife habitat loss and encroachment; human-wildlife interactions; forest fragmentation; exotic and invasive pests; and potential changes in forest productivity that result when forested areas become part of the WUI. The scope and seriousness of the WUI issue is still unclear, in part because the WUI itself can be defined in many different ways. Research focusing on WUI issues could benefit managers by determining where the WUI is currently located, and for this purpose we are working to map and analyze the WUI across the United States, and to examine its dynamics over time.

Mapping the Wildland Urban Interface in the United States

Our WUI definition follows the Federal Register, and we identify intermix and interface types of WUI (Teie and Weatherford 2000; USDA and USDI 2001). The two components used here to define the WUI are (a) human presence, measured using housing data from the block-level housing unit counts from the decennial censuses; and (b) wildland vegetation, assessed with the 1992/3 National Land Cover dataset (NLCD) (Vogelmann et al. 2001). For a given census block to be intermix WUI, it must be 'vegetated' and have more than 6.16 housing units/km2 (more than 1 house per 40 acres). A census block is 'vegetated' if more than 50 percent of its landcover is classified as forest, shrub, native grassland, transitional or wetland. All other census blocks, including those dominated by agriculture or orchards, are classified as 'non-vegetated' and are not included in the intermix WUI. Interface WUI does not depend on vegetation within the census block. It must have more than 6.16 housing units/km2 and lie within 2.414 km (1.5 miles) of an area (made up of one or more contiguous Census blocks) that is at least 75 percent 'vegetated' and larger than 5 km2 (1,325 acres). Using these criteria, we find that the WUI is widespread across the country, covering almost 10 percent of the land base in the lower 48 states and encompassing 37 percent of all homes. In some eastern states, lands classified as WUI make up more than half the total land area in the state. Western states have smaller proportions of their land classified as WUI, but well over the majority of the homes are located within its boundaries. Intermix WUI is concentrated in the East, South, and Midwest; interface is more typical of the West, though New York and Pennsylvania have extensive interface, too.

The WUI tends to be concentrated in and around metropolitan areas, and suburban WUI is widespread and a major component of the entire WUI in each state. While city centers are too densely settled to reach the 50 percent vegetation threshold, the wide ring of suburban and exurban areas surrounding urban centers is often part of the WUI. Our analysis of 12 metropolitan areas (i.e., cities plus surrounding areas, as designated by the Census Bureau) across the U.S. shows that in each, the percentage of the land base classified as WUI is greater than that in the rest of the state (table 1). This holds true across the country; despite major regional differences in the character of the WUI, its area is always concentrated in metropolitan areas. For example, in Atlanta, 54 percent of the land area is classified as WUI, while across the rest of Georgia, just 19 percent of land is in the WUI. The proportion of homes in the WUI is more mixed across these metropolitan regions, with only 4 of the 12 metropolitan areas having a higher percentage of their homes in the WUI than their respective states. Looking again at Atlanta, 52 percent of homes are in the WUI, while 55 percent of homes across the rest of the state are in the WUI.

Conclusion

The WUI is defined as the area where houses and wildland vegetation meet or intermingle. These conditions are met in many cities and suburbs, especially in those neighborhoods built in recent decades under zoning regulations requiring large lots, catering to home buyers who want more space. The work urban foresters have done to establish and maintain urban forests, their efforts to teach developers how to preserve existing vegetation, and the trend toward maintaining open space in and around housing developments are all reflected in the current size of the WUI. The consistent preference Americans express for living in small towns (Brown et al. 1997) and their ability to act on that preference are manifested in the extent of the WUI. A house in the WUI is a mainstay of the 21st Century American dream.

The concentration of the WUI in metropolitan areas suggests that urban foresters and wildland resource managers must both address WUI issues. The extent of the WUI in metropolitan areas is a sign that urban foresters are making cities greener, more pleasant and healthier places to live. But with this success comes a need to face the particular challenges associated with the WUI. Fire, wildlife management, forest health, and many other issues must be dealt with in the rich social context of growing urban and suburban communities.

Table 1. The Wildland –Urban Interface (WUI) in Metropolitan Regions and in the Remainder of the State

	Area of WUI		**Houses in WUI**	
Metro and State	**Metro**	**Remainder of State**	**Metro**	**Remainder of State**
	Percent			
Atlanta, GA	54.3	19.0	52.3	55.4
Austin, TX	30.5	4.5	69.5	25.7
Boston, MA[1]	76.0	60.5	47.1	67.5
Chicago, IL[1]	5.9	1.8	8.4	4.7
Denver, CO	10.2	2.2	34.0	61.5
Jacksonville, FL	31.1	17.8	40.4	25.7
Los Angeles, CA	21.7	6.7	28.6	48.6
Phoenix, AZ	6.1	2.5	43.4	71.7
Portland, OR[1]	10.6	2.8	32.8	52.2
Salt Lake City, UT	2.9	1.3	41.6	68.7
San Diego, CA	22.2	6.8	50.9	40.8
Seattle, WA	25.2	7.1	35.7	63.4

Note. US Census Bureau-designated standard areas were used to define metros.
1. These metropolitan areas extend beyond one state, and counties in adjacent states were excluded.

References

Brown, D.L., G.V. Fuguitt, T.B. Heaton, S. Waseem. 1997. Continuities in size of place preferences in the United States, 1972-1992. Rural Sociology, 62(4): 408-428.

Cohen, J.D. 1991. A site-specific approach for assessing the fire risk to structures at the wildland/urban interface. In: S.C. Novdin & T.A. Waldrop (eds.). Fire and the Environment: Ecological and Cultural Perspectives. GTR SE-069: 252-255.

Heimlich, R.E., W.D. Anderson. 2001. Development at the urban fringe and beyond: impacts on agriculture and rural land. ERS Agricultural Economic Report No. 803, U.S. Department of Agriculture, Economic Research Service, Washington, DC (Available online: http://www.ers.usda.gov/publications/aer803/).

Macie, E.A., Hermansen, L.A., eds. 2002. Human Influences on Forest Ecosystems: The Southern Wildland-Urban Interface Assessment. General Technical Report SRS-55, U.S. Department of Agriculture, Forest Service, Southern Research Station, Athens, GA.

Teie, W.C., B.F. Weatherford. 2000. Fire in the west: The wildland/urban interface fire problem. Report to the Council of Western State Foresters. Rescue, CA: Deer Valley Press.

Vogelmann, J.E., S.E. Howard, L. Yang, C.R Larson, B.K. Wylie, N. van Driel. 2001. Completion of the 1990s National Land Cover Data set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogr. Eng. & Remote Sensing 67: 650-662.

U.S. Department of Agriculture, U.S. Department of the Interior. 2001. Urban Wildland Interface Communities Within The Vicinity Of Federal Lands That Are At High Risk From Wildfire. Federal Register 66: 751.

Citation

[1] Definitions and information about the Census Bureau's metropolitan designation can be found at http://www.census.gov/population/www/estimates/aboutmetro.html

Ecological Applications, 15(3), 2005, pp. 799–805

THE WILDLAND–URBAN INTERFACE IN THE UNITED STATES

V. C. Radeloff,[1,5] R. B. Hammer,[2] S. I. Stewart,[3] J. S. Fried,[4] S. S. Holcomb,[1] and J. F. McKeefry[1]

[1]*Department of Forest Ecology and Management, University of Wisconsin-Madison, 1630 Linden Drive, Madison, Wisconsin 53706 USA*
[2]*Department of Rural Sociology, University of Wisconsin-Madison, Madison, Wisconsin 53706 USA*
[3]*USDA Forest Service, North Central Research Station, Evanston, Illinois 60201 USA*
[4]*USDA Forest Service, Pacific Northwest Research Station/FIA, Portland, Oregon 97205 USA*

Abstract. The wildland–urban interface (WUI) is the area where houses meet or intermingle with undeveloped wildland vegetation. The WUI is thus a focal area for human–environment conflicts, such as the destruction of homes by wildfires, habitat fragmentation, introduction of exotic species, and biodiversity decline. Our goal was to conduct a spatially detailed assessment of the WUI across the United States to provide a framework for scientific inquiries into housing growth effects on the environment and to inform both national policy-makers and local land managers about the WUI and associated issues. The WUI in the conterminous United States covers 719 156 km^2 (9% of land area) and contains 44.8 million housing units (39% of all houses). WUI areas are particularly widespread in the eastern United States, reaching a maximum of 72% of land area in Connecticut. California has the highest number of WUI housing units (5.1 million). The extent of the WUI highlights the need for ecological principles in land-use planning as well as sprawl-limiting policies to adequately address both wildfire threats and conservation problems.

Key words: fragmentation; housing growth; urban sprawl; urbanization; wildfire; wildland fire; wildland–urban interface.

Introduction

Urban and suburban development in or near wildland vegetation poses a major threat to the environment (Johnson 2001). Housing development causes habitat loss and fragmentation (Theobald et al. 1997), threatens wildlife populations (Soulé 1991), and results in biodiversity declines (McKinney 2002). It has been estimated that >50% of all federally listed threatened and endangered species in the United States are in peril due to urbanization (Czech et al. 2000). These problems are of particular concern in the wildland–urban interface (WUI), where homes and associated structures are built among forests, shrubs, or grasslands.

The WUI has received considerable attention because of recent increases in both the number of structures destroyed and the area burned annually by wildland fire (NIFC 2004). It is in the WUI where protection of structures from wildland fires is most challenging (Cohen 2000, Winter and Fried 2001) and where human-caused fire ignitions are most common (Cardille et al. 2001). Human-caused fires burned 43% of the record-setting 34 083 km^2 that were burned in the United States during the 2000 fire season (NIFC 2004). In 2003, over 4200 homes in the United States were destroyed by wildland fires, nearly all of them during the October fires in southern California, resulting in more than two billion U.S. dollars in damages (NIFC 2004). The wildland fire threat to houses was one major impetus for new, and highly controversial, U.S. legislation purportedly aimed at restoring forest health, which focuses on reducing fuel loads (Service 2003). Housing development in the WUI is thus of concern both for wildland fire issues (Covington 2000) and for conservation in general (McKinney 2002).

Housing growth in the United States has been strong in recent decades. During the 1990s, 13.6 million new housing units were built in the United States (13% growth). Americans' affinity for rural settings (Sullivan 1994, Brown et al. 1997) has increased development in exurban and rural areas (Theobald 2001, Hansen et al. 2002, Radeloff et al. 2005). A significant portion of new development occurs at low and medium density and tends to be more dispersed, thus affecting a larger area per housing unit when assuming a disturbance zone with a fixed radius around each house (Theobald et al. 1997, Hammer et al. 2004). Furthermore, housing growth is particularly high in areas that are rich in natural amenities (Johnson and Beale 1994), such as forests (Radeloff et al. 2005), lakes (Radeloff et al. 2001, Schnaiberg et al. 2002), and seashores (Bartlett et al. 2000), or are adjacent to protected areas (Rasker and Hansen 2000). As development pressure mounts in the WUI, environmental problems associated with it may increase.

Despite the significance of the WUI both in the current debate on fire policy and fuel treatment, and for environmental quality in general, empirical data on its

Manuscript received 9 September 2004; revised 4 November 2004; accepted 6 November 2004. Corresponding Editor: G. H. Aplet.
[5] E-mail: radeloff@wisc.edu

extent and location are lacking. Our goal was to conduct a spatially detailed national assessment of the WUI across the conterminous United States. By doing so, we wanted to provide a framework for scientific inquiries into the effects of housing growth on the environment and to inform both national policymakers and local land managers about the WUI and associated issues.

Methods

WUI definition and assessment

Our approach to mapping the WUI was based on an existing WUI definition published in the Federal Register (USDA and USDI 2001), which we applied across the conterminous United States using fine-resolution housing density and land cover data in a Geographic Information System (GIS). The WUI definition in the Federal Register was developed to identify communities at risk in the vicinity of public lands. According to this definition, ''the Wildland–Urban Interface is the area where houses meet or intermingle with undeveloped wildland vegetation'' (USDA and USDI 2001). Areas where houses and wildland vegetation intermingle are referred to as intermix WUI. Developed areas that abut wildland vegetation are characterized as interface WUI. Although this definition was developed in conjunction with wildland fire policy, it does not explicitly account for differences in fire risk.

Assessing the WUI requires detailed data on housing density. According to the Federal Register definition, WUI areas must contain at least 6.17 housing units/km^2 (or 1 house/40 acres). No maximum housing density is set. We analyzed housing unit counts from the U.S. 2000 decennial census at the census block level. As defined by the U.S. Census Bureau, a housing unit may be a house, an apartment, or a mobile home, and can be occupied or vacant; thus, seasonal homes are included (U.S. Census Bureau 2002). Housing unit counts represent a complete enumeration. Census blocks are generally delineated based on physical features, such as roads and rivers. Blocks vary in size; the median size is 0.01 km^2 and the maximum reaches 2700 km^2 in areas with no housing units.

In addition to housing density, the WUI assessment required fine-resolution vegetation data. We derived vegetation information from the U.S. Geological Survey (USGS) National Land Cover Data (NLCD), which represents classified 30-m resolution Landsat TM satellite data from 1992 for the 48 conterminous states of the United States (Vogelmann et al. 2001). We defined as wildland vegetation the following land cover classes: coniferous, deciduous, and mixed forest; shrubland; grasslands/herbaceous; transitional; and woody and emergent herbaceous wetlands. Excluded from wildland vegetation were low- and high-intensity residential, commercial/industrial, orchards/vineyards, pasture/hay, row crops, small grains, fallow, urban/recreational grasses, bare rock/sand/clay, quarries, open water, and perennial ice/snow. Using a GIS, we calculated the housing density and percentage of wildland vegetation for each census block.

The Federal Register definition distinguishes between intermix and interface WUI. Intermix WUI is defined in the Federal Register as an area above a threshold of 6.17 housing units/km^2 that is dominated by wildland vegetation. We set the threshold for wildland vegetation at 50% of the terrestrial area of a given census block. Interface WUI is characterized by the Federal Register definition as developed areas in the vicinity of wildland vegetation. Thus, we mapped as interface WUI all census blocks above 6.17 housing units/km^2 that contained $<$50% wildland vegetation, but were within 2.4 km of an area that is heavily vegetated ($>$75% wildland vegetation) and larger than 5 km^2. The 2.4-km distance follows the recommendation of the California Fire Alliance (2001) and represents an estimate of the distance a firebrand can fly ahead of a fire front. If a census block was only partially within the 2.4-km distance, then the census block was split, and only the portion within 2.4 km was included as interface. We set a minimum-size threshold at 5 km^2 for the areas that are heavily vegetated to avoid including residential areas that are within 2.4 km of small urban parks.

Sensitivity analysis

Our WUI assessment was heavily based on thresholds, which were mostly set by the Federal Register definition. We thus conducted a sensitivity analysis to test the robustness of the estimates of WUI area and WUI houses. Thresholds for housing density, intermix vegetation, and the interface buffer distance were increased by 100% or decreased by 50%; land cover classes used to identify wildland vegetation were progressively reduced to ultimately include only forests.

The minimum housing density threshold of 6.17 housing units/km^2 in the Federal Register definition was both doubled (12.34 housing units/km^2) and halved (3.09 housing units/km^2) in the sensitivity analysis. The minimum wildland vegetation threshold required for intermix WUI was 50% for our national assessment. In the sensitivity analysis, we tested both a 25% and a 75% minimum wildland vegetation threshold. The maximum buffer distance for interface WUI in the national assessment was 2.4 km, which was both doubled (4.8 km) and halved (1.2 km) in the sensitivity analysis. The land cover class list used to define wildland vegetation in the national assessment was reduced to two levels in the sensitivity analysis. The ''upland'' scenario excluded woody and emergent wetlands from the full list of wildland vegetation classes. The ''forest'' scenario included only coniferous, deciduous, and mixed forest as wildland vegetation classes. Potential interactive effects among these variables were examined via minimum and maximum WUI estimates. The

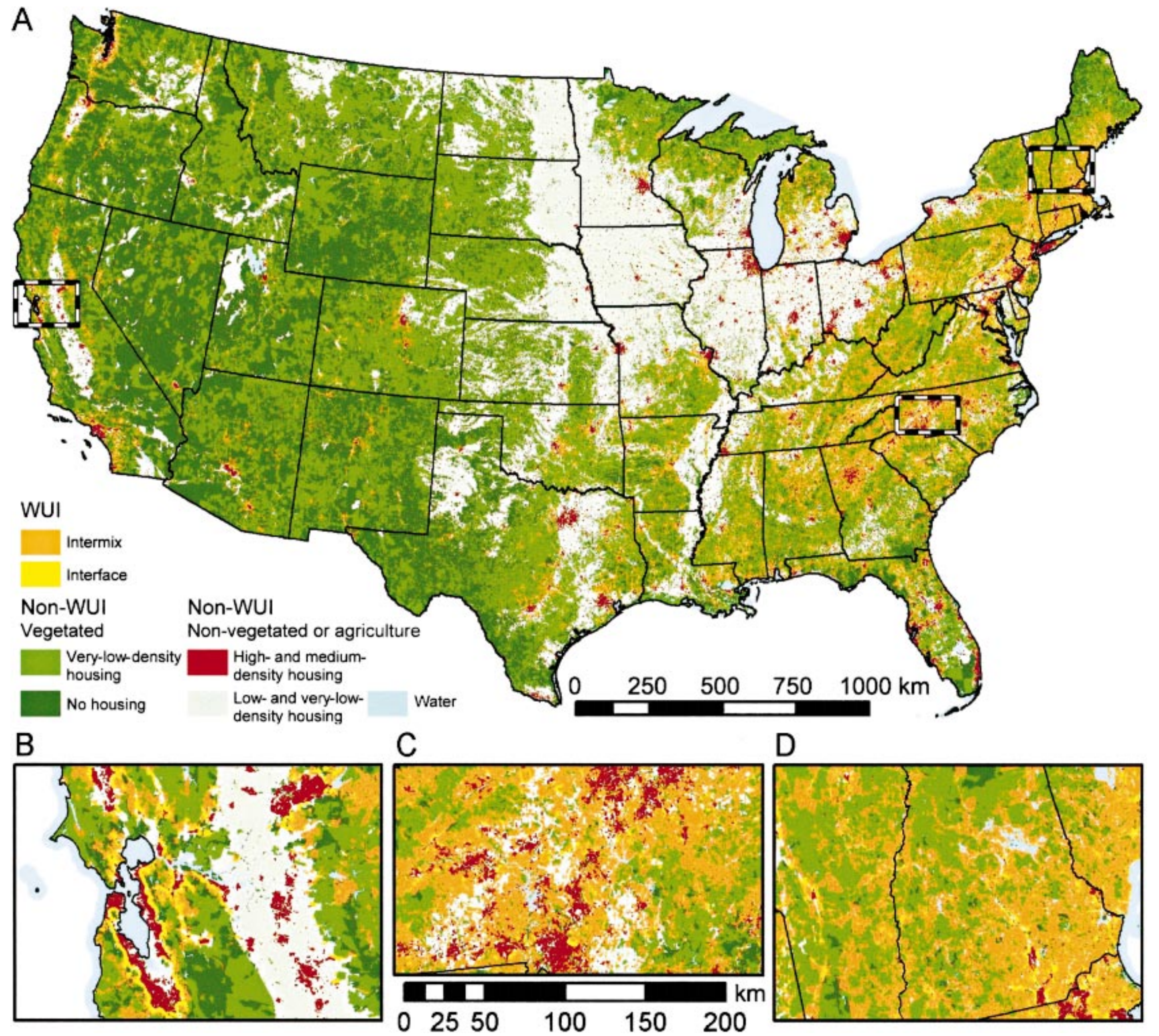


FIG. 1. The wildland–urban interface (WUI) in 2000 in (A) the conterminous United States, (B) the San Francisco Bay area, (C) North Carolina, and (D) New Hampshire. Housing density figures are as follows: very low, >0–6.17 housing units/km^2; low, 6.17–49.42; medium, 49.42–741.31; and high, >741.31 (USDA and USDI 2001).

minimum WUI estimate represents a housing density threshold of 12.34 housing units/km^2, an intermix vegetation threshold of 75%, an interface buffer distance of 1.2 km, and only forest vegetation classes. The maximum WUI estimate represents a housing density threshold of 3.09 housing units/km^2, an intermix vegetation threshold of 25%, an interface buffer distance of 4.8 km, and the original set of all wildland vegetation classes.

RESULTS

Across the conterminous United States, the WUI covers 719 156 km^2 (9.4% of the land area) and contains 44 348 628 housing units (38.5% of all housing units). All 48 states contain WUI areas, but the eastern United States has the greatest extent, especially in northern Florida, the southern Appalachians, and coastal areas of the Northeast (Fig. 1A in the Appendix; data are publicly available online).[6] Major WUI areas are also located along the West Coast, the Colorado Front Range, southeast Texas, and the northern Great Lakes States. WUI is common at the fringe of major metropolitan centers such as Los Angeles, San Francisco (Fig. 1B), Seattle, Denver, Dallas, Atlanta, Washington D.C., New York, and Boston. WUI is also widespread in rural areas without major metropolitan centers that are rich in natural amenities, such as the Sierra Nevada foothills (Fig. 1B), the northern Great Lakes States, southern Appalachia (Fig. 1C), and rural New England (Fig. 1D).

State-level analysis shows that the number of homes in the WUI in a single state reaches up to 5.1 million (California), and the WUI land area up to 55 280 km^2

[6] ⟨http://www.silvis.forest.wisc.edu/projects/WUI_Main.asp⟩

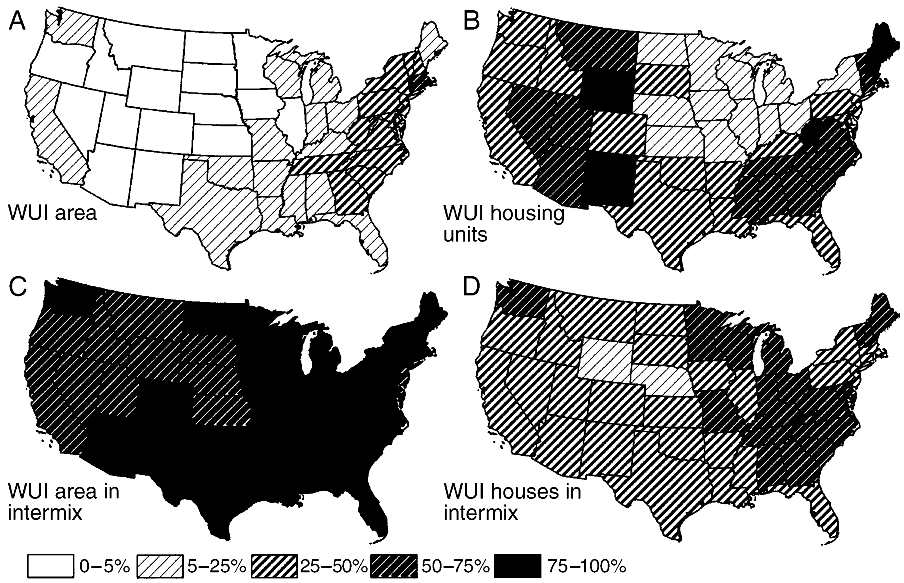


FIG. 2. WUI characteristics at the state level: (A) WUI area as a percentage of total land area, (B) WUI housing units as a percentage of all housing units, (C) percentage of the WUI area that is intermix WUI, and (D) percentage of WUI houses that are in intermix WUI.

(North Carolina). At the state level, the proportion of land area in the WUI reaches 72.4% (Connecticut), and the maximum proportion of housing units in the WUI is 83.5% (New Hampshire). WUI area by state shows a strong east–west gradient, with the highest proportions in the East (Fig. 2A). The proportion of homes in the WUI is high in both the East and the West. In the Midwest, <25% of homes are found in the WUI because wildland vegetation is not as common in these agriculturally dominated states (Fig. 2B). Extensive metropolitan areas also tend to limit the proportion of a state's homes in the WUI even though the absolute number of homes in the WUI can be high (e.g., California).

When we break the WUI into its two components, intermix accounts for the majority of WUI area nationally (80.7%; Fig. 2C). Interface WUI is commonly limited to a ring separating non-WUI urban centers from outlying intermix areas (Fig. 1B). However, interface WUI does not occur around all urban centers, as illustrated by its absence around cities of the Southeast (Fig. 1C). Across the conterminous United States, housing units are almost evenly split between interface and intermix WUI (53.4% vs. 46.6%) partly because housing densities are higher in the interface. In most southeastern states, WUI housing units are predominantly in intermix WUI (Fig. 2D). Interface WUI is more common in western states, occupying up to a third of the WUI area and containing up to two-thirds of the WUI houses.

Sensitivity analysis

Results of the sensitivity analysis show that the WUI assessment is fairly robust (Table 1). Major changes in single variables (e.g., +100%, −50%) generally result in <50% change in WUI area or WUI housing units. The only exception to this rule is California, where WUI houses decline by 88% if wildland vegetation is limited to forests, and shrublands are excluded. However, given the high frequency and intensity of fire in chaparral communities, shrublands must be included in any realistic definition of wildland vegetation.

In all three states, WUI area is most sensitive to the housing-density threshold. The number of WUI housing units is most sensitive to changes in the buffer distance that defines interface WUI (California, New Hampshire) or the intermix vegetation threshold (North Carolina). Under the maximum WUI scenario (Table 1), both WUI area and WUI housing units increase by up to 60%, and even under the minimum WUI scenario, there are 384 000 housing units in the WUI in California. The ranking of the states in terms of their WUI area and WUI houses remains constant across all scenarios, suggesting that the general spatial pattern, for example, of more abundant WUI in the East as compared to the West, are not an artifact of the WUI definition that we employed.

DISCUSSION

Housing development in or near wildland vegetation is widespread: about one-tenth of the area and one-third of the housing units of the conterminous United States are located in the WUI. The pervasiveness of the WUI has immediate relevance in the current U.S. debate on wildland fire, fuel treatments, and the restoration of fire dependent forest ecosystems (Covington 2000, Service 2003). The WUI is where wildland fires destroy the most structures when fuels and weather are

TABLE 1. Changes in the wildland–urban interface (WUI) area and WUI housing units in California, North Carolina, and New Hampshire, USA, in response to changes in the WUI definition thresholds tested in the sensitivity analysis.

Variable	California Area (1000s km²)	California Houses (100 000s housing units)	North Carolina Area (1000s km²)	North Carolina Houses (100 000s housing units)	New Hampshire Area (1000s km²)	New Hampshire Houses (100 000s housing units)
Federal Register definition†	29.3	50.9	55.3	23.2	9.6	4.5
Housing density						
>3.09‡	41.1	51.4	74.0	24.1	13.5	4.6
>12.34	20.7	50.1	33.5	21.3	5.9	4.1
Intermix vegetation						
>25%	30.7	58.0	62.8	27.9	9.7	4.6
>75%	28.6	49.0	47.5	20.6	9.5	4.4
Interface distance						
<4.8 km	33.0	74.7	59.3	28.3	9.7	5.2
<1.2 km	26.4	35.2	52.3	19.8	9.4	3.9
Wildland vegetation						
Upland only†	29.1	50.5	45.4	18.8	9.4	4.0
Forest only†	10.0	6.2	44.8	18.5	9.4	4.0
Minimum WUI†	4.6	3.8	5.0	2.8	5.0	2.8
Maximum WUI†	46.5	79.1	83.1	28.1	13.6	5.4

† See *Methods: WUI definition and assessment* for definition.
‡ Housing units per km².

conducive to fire (Covington 2000) and where human-caused fire ignitions are most common (Cardille et al. 2001). The southern California fires of 2003 highlighted the devastating effects that wildland fires can have in WUI areas. Yet, these fires, despite setting records, burned only a small portion of the WUI of southern California, leaving extensive areas of the WUI at risk for future fires. This emphasizes the magnitude of the task that is at hand and suggests that sprawl-limiting policies may have to be paired with fuel treatments to substantially lower the fire threat to homes in the long term.

When interpreting our results with respect to fire, it is important to remember that the Federal Register WUI definition we used is a general one and does not assess wildland fire risk specifically. For example, WUI areas in southern California that are dominated by chaparral communities with short fire-return intervals are perhaps the most prone to fire of all WUI areas in the United States. (Minnich 1983, Keeley et al. 1999, Fried et al. 2004). Conversely, WUI areas in New Hampshire that are located in mesic hardwood forests are much less likely to experience wildland fire (Fig. 1D; Foster and Zebryk 1993). In addition to fire frequency, WUI areas differ in their fire regimes (e.g., frequent but low-intensity surface fire vs. infrequent but catastrophic crown fire) depending on weather patterns, vegetation structure, fuel loads, and topography (Heinselman 1981). And whether a home will burn in the event of a wildfire will depend on its building materials (e.g., cedar shingles vs. sheet-metal roofing), landscaping features, and accessibility to firefighting equipment (Cohen 2000). Our WUI assessment needs to be integrated with spatially detailed data on these factors to estimate fire threat in the United States WUI. Such data are not yet available across the United States, but we have conducted a fire threat ranking for smaller regions (Haight et al. 2004).

The WUI assessment also raises broader issues that reach beyond wildland fire. Numerous case studies show that housing in or near wildland vegetation (and correlates, such as human populations and roads) have profound effects on biodiversity and ecosystems, and that these effects are largely negative (McKinney 2002). Areas with high housing and road densities exhibit lower populations of neotropical migrant birds (Friesen et al. 1995, Cam et al. 2000, Kluza et al. 2000), wolves (Mladenoff et al. 1995), and other large carnivores (Rasker and Hackman 1996). Species richness of butterflies (Blair 1999), birds (Clergeau et al. 1998, Germaine et al. 1998), and mammals (Joly and Myers 2001) is lower where human population density is high. Accordingly, the number of endangered species tends to be higher where human activities are more prevalent (Czech et al. 2000, Sechrest et al. 2002).

At the landscape scale, housing development is a major cause of habitat loss and fragmentation (Theobald et al. 1997, Swenson and Franklin 2000, Radeloff et al. 2005), due in part to new roads built to access homes (Hawbaker and Radeloff 2004). Fragmentation, in turn, causes local extinction and biodiversity declines by reducing the size of habitat patches and of remnant populations (Andrén 1994).

However, not all species decline in response to housing growth. Both human commensals and exotic species may thrive in the WUI (Allen and O'Connor 2000, Johnson 2001, Langton et al. 2001, Odell and Knight 2001). During construction, habitat conditions favor disturbance-adapted species, and subsequent landscaping around houses often introduces exotic plant species to neighboring ecosystems (Suarez et al. 1998, Pysek et al. 2002). The facilitation of exotic species spread is one of the major processes through which humans affect ecosystems (Vitousek et al. 1997).

There is ample evidence that WUI housing profoundly affects the environment, yet much of what we know about the impacts of housing development has been learned by studying environmental response along urban-to-rural gradients (McDonnell and Pickett 1990). Our results suggest the need for additional research focused on the dispersed housing development typical of intermix type WUI, which covers an extensive and growing area of the U.S. Human–environment conflicts in the WUI are likely to increase in the future, especially if past housing-growth trends continue in rural areas that are rich in natural amenities (Theobald 2001, Hammer et al. 2004, Radeloff et al. 2005). Given these problems, the WUI should be a focus of national discussions on natural resource issues and policies. The pervasiveness of the WUI highlights the value of protected areas, and the need to quickly identify and secure priority sites for conservation in the face of strong development pressure in rural areas. In addition, our results highlight the importance of extending conservation efforts to private lands (Norten 2000), and integrating ecological principles in land-use planning (Broberg 2003) and zoning decisions to maintain key habitats and the corridors that connect protected areas. Solving both wildfire and conservation problems will require landscape-level planning across ownership boundaries, and a broad vision for the future of wildlands and rural areas.

COMMUNICATIONS

Acknowledgments

We are most grateful for comments on the manuscript by L. Burde, J. F. Dwyer, E. J. Gustafson, C. C. Lepczyk, R. E. McRoberts, D. J. Mladenoff, A. M. Pidgeon, and two anonymous reviewers. Financial support was provided by the North Central Research Station, the Pacific Northwest Forest Inventory and Analysis Program, and the Northern Global Change Program of the USDA Forest Service under the National Fire Plan.

Literature Cited

Allen, A. P., and R. J. O'Connor. 2000. Interactive effects of land use and other factors on regional bird distributions. Journal of Biogeography **27**:889–900.

Andrén, H. 1994. Effects of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos **71**:355–366.

Bartlett, J. G., D. M. Mageean, and R. J. O'Connor. 2000. Residential expansion as a continental threat to U.S. coastal ecosystems. Population and Environment **21**:429–468.

Blair, R. B. 1999. Birds and butterflies along an urban gradient: surrogate taxa for assessing biodiversity? Ecological Applications **9**:164–170.

Broberg, L. 2003. Conserving ecosystems locally: a role for ecologists in land-use planning. BioScience **53**:670–673.

Brown, D. L., G. V. Fuguitt, T. B. Heaton, and S. Waseem. 1997. Continuities in size of place preferences in the United States, 1972–1992. Rural Sociology **62**:408–428.

California Fire Alliance. 2001. Characterizing the fire threat to wildland-urban interface. California Fire Alliance, Sacramento, California, USA.

Cam, E., J. D. Nichols, J. R. Sauer, J. E. Hines, and C. H. Flather. 2000. Relative species richness and community completeness: birds and urbanization in the mid-Atlantic states. Ecological Applications **10**:1196–1210.

Cardille, J. A., S. J. Ventura, and M. G. Turner. 2001. Environmental and social factors influencing wildfires in the Upper Midwest, United States. Ecological Applications **11**:111–127.

Clergeau, P., J. P. L. Savard, G. Mennechez, and G. Falardeau. 1998. Bird abundance and diversity along an urban-rural gradient: a comparative study between two cities on different continents. Condor **100**:413–425.

Cohen, J. D. 2000. Preventing disaster: home ignitability in the wildland-urban interface. Journal of Forestry **98**:15–21.

Covington, W. W. 2000. Helping western forests heal. Nature **408**:135–136.

Czech, B., P. R. Krausman, and P. K. Devers. 2000. Economic associations among causes of species endangerment in the United States. BioScience **50**:593–601.

Foster, D. R., and T. M. Zebryk. 1993. Long-term vegetation dynamics and disturbance history of a tsuga-dominated forest in New England. Ecology **74**:982–998.

Fried, J. S., C. L. Bolsinger, and D. Beardsley. 2004. Chaparral in southern and central coastal California in the mid-1990s: area, ownership, condition, and change. USDA Forest Service PNW-RB-240, Portland, Oregon, USA.

Friesen, L. E., P. F. J. Eagles, and R. J. MacKay. 1995. Effects of residential development on forest dwelling neotropical migrant songbirds. Conservation Biology **9**:1408–1414.

Germaine, S. S., S. S. Rosenstock, R. E. Schweinsburg, and W. S. Richardson. 1998. Relationships among breeding birds, habitat, and residential development in greater Tucson, Arizona. Ecological Applications **8**:680–691.

Haight, R. G., D. T. Cleland, R. B. Hammer, V. C. Radeloff, and T. S. Rupp. 2004. Assessing fire risk in the wildland urban interface—a landscape ecosystem approach. Journal of Forestry **102**:41–48.

Hammer, R. B., S. I. Stewart, R. Winkler, V. C. Radeloff, and P. R. Voss. 2004. Characterizing spatial and temporal residential density patterns across the U.S. Midwest, 1940–1990. Landscape and Urban Planning **69**:183–199.

Hansen, A. J., R. Rasker, B. Maxwell, J. J. Rotella, J. D. Johnson, A. W. Parmenter, L. Langner, W. B. Cohen, R. L. Lawrence, and M. P. V. Kraska. 2002. Ecological causes and consequences of demographic change in the new West. Bioscience **52**:151–162.

Hawbaker, T. J., and V. C. Radeloff. 2004. Road and landscape pattern in northern Wisconsin based on a comparison of four road data sources. Conservation Biology **18**:1233–1244.

Heinselman, M. L. 1981. Fire and fire succession in the conifer forests of northern North America. Pages 372–405 *in* D. C. West, H. H. Shugart, and D. B. Botkin, editors. Forest succession: concepts and application. Springer Verlag, New York, New York, USA.

Johnson, K. M., and C. L. Beale. 1994. The recent revival of widespread population-growth in nonmetropolitan areas of the United States. Rural Sociology **59**:655–667.

Johnson, M. P. 2001. Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environment and Planning A **33**:717–735.

Joly, K., and W. L. Myers. 2001. Patterns of mammalian species richness and habitat associations in Pennsylvania. Biological Conservation **99**:253–260.

Keeley, J. E., C. J. Fotheringham, and M. Morais. 1999. Reexamining fire suppression impacts on brushland fire regimes. Science **284**:1829–1832.
Kluza, D. A., C. R. Griffin, and R. M. Degraaf. 2000. Housing developments in rural New England: effects on forest birds. Animal Conservation **3**:15–26.
Langton, S. D., D. P. Cowan, and A. N. Meyer. 2001. The occurrence of commensal rodents in dwellings as revealed by the 1996 English house condition survey. Journal of Applied Ecology **38**:699–709.
McDonnell, M. J., and S. T. A. Pickett. 1990. Ecosystem structure and function along urban rural gradients: an unexploited opportunity for ecology. Ecology **71**:1232–1237.
McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. BioScience **52**:883–890.
Minnich, R. A. 1983. Fire mosaics in southern California and northern Baja California. Science **219**:1287–1294.
Mladenoff, D. J., T. A. Sickley, R. G. Haight, and A. P. Wydeven. 1995. A regional landscape analysis and prediction of favorable gray wolf habitat in the northern great lakes region. Conservation Biology **9**:279–294.
NIFC (National Interagency Fire Center). 2004. Wildland fire statistics. ⟨www.nifc.gov›⟩ (last accessed 27 January 2004).
Norten, D. A. 2000. Conservation biology and private land: shifting the focus. Conservation Biology **14**:1221–1223.
Odell, E. A., and R. L. Knight. 2001. Songbird and medium-sized mammal communities associated with exurban development in Pitkin County, Colorado. Conservation Biology **15**:1143–1150.
Pysek, P., V. Jarosik, and T. Kucera. 2002. Patterns of invasion in temperate nature reserves. Biological Conservation **104**:13–24.
Radeloff, V. C., R. B. Hammer, and S. I. Stewart. 2005. Sprawl and forest fragmentation in the U.S. Midwest from 1940 to 2000. Conservation Biology, *in press.*
Radeloff, V. C., R. B. Hammer, P. R. Voss, A. E. Hagen, D. R. Field, and D. J. Mladenoff. 2001. Human demographic trends and landscape level forest management in the northwest Wisconsin Pine Barrens. Forest Science **47**:229–241.
Rasker, R., and A. Hackman. 1996. Economic development and the conservation of large carnivores. Conservation Biology **10**:991–1002.
Rasker, R., and A. J. Hansen. 2000. Natural amenities and populations growth in the Greater Yellowstone region. Human Ecology Review **7**:30–40.
Schnaiberg, J., J. Riera, M. G. Turner, and P. R. Voss. 2002. Explaining human settlement patterns in a recreational lake district: Vilas County, Wisconsin, USA. Environmental Management **30**:24–34.
Sechrest, W., T. M. Brooks, G. A. B. Da Fonseca, W. R. Konstant, R. A. Mittermeier, A. Purvis, A. B. Rylands, and J. L. Gittleman. 2002. Hotspots and the conservation of evolutionary history. Proceedings of the National Academy of Sciences (USA) **99**:2067–2071.
Service, R. F. 2003. Critics say new law is a bit thin on science. Science **302**:1879.
Soulé, M. E. 1991. Land-use planning and wildlife maintenance: guidelines for conserving wildlife in an urban landscape. Journal of the American Planning Association **57**: 313–323.
Suarez, J. G., D. T. Bolger, and T. J. Case. 1998. Effects of fragmentation and invasion on native ant communities in coastal southern California. Ecology **79**:2041–2056.
Sullivan, W. C. 1994. Perceptions of the rural-urban fringe: citizen preferences for natural and developed settings. Landscape and Urban Planning **29**:85–101.
Swenson, J. J., and J. Franklin. 2000. The effects of future urban development on habitat fragmentation in the Santa Monica Mountains. Landscape Ecology **15**:713–730.
Theobald, D. M. 2001. Land use dynamics beyond the urban fringe. Geographical Review **91**:544–564.
Theobald, D. M., J. R. Miller, and N. T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. Landscape and Urban Planning **39**:25–36.
U.S. Census Bureau. 2002. Summary file 3A technical documentation. U.S. Census Bureau, Washington, D.C., USA.
USDA and USDI. 2001. Urban wildland interface communities within vicinity of Federal lands that are at high risk from wildfire. Federal Register **66**:751–777.
Vitousek, P. M., H. A. Mooney, J. Lubchenko, and J. M. Melillo. 1997. Human domination of Earth's ecosystems. Science **277**:494–499.
Vogelmann, J. E., S. M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and N. van Driel. 2001. Completion of the 1990s National Land Cover Data Set for the conterminous United States from Landsat Thematic Mapper data and ancillary data sources. Photogrammetric Engineering and Remote Sensing **67**:650–662.
Winter, G. J., and J. S. Fried. 2001. Estimating contingent values for protection from wildland fire using a two-stage decision framework. Forest Science **47**:349–360.

APPENDIX

A table showing the amount and the relative abundance of wildland–urban interface (WUI) area and WUI houses (both in the intermix and the interface WUI type) in each state of the conterminous United States is available in ESA's Electronic Data Archive: *Ecological Archives* A015-020-A1.

Working with Neighborhood Organizations to Promote Wildfire Preparedness

Holly Johnson Shiralipour
Brooker Creek Preserve Environmental Education Center
Tarpon Springs, FL

Martha C. Monroe
School of Forest Resources and Conservation
University of Florida, Gainesville, FL (mcmonroe@ufl.edu)

Kristen C. Nelson and Michelle Payton
College of Food, Agricultural and Natural Resource Sciences
University of Minnesota, St. Paul, MN (kcn@umn.edu)

Introduction

The structure of neighborhood organizations can encourage resident participation in a range of activities, which suggests that neighborhood organizations may be one of the more effective ways to involve people in adopting wildfire preparedness actions. Examples of neighborhood organizations include homeowner associations, neighborhood councils, and volunteer fire departments. Using established neighborhood organizations potentially offers several advantages over forming new groups or working with service and church-based organizations, social groups, and sport clubs. This has been recognized by a growing number of government agencies, nonprofit organizations, and fire departments that are working with neighborhoods to promote wildfire preparedness (Boura 1998, McGee and Russell 2003, NWCG 1998). This research project was designed to learn about the role neighborhood organizations play in helping people reduce their wildfire risk. Results show these groups are a readymade physical, social, and political entity capable of playing that important role.

In this paper we present insights developed in interviews with leaders of the local neighborhood organizations and employees of community fire departments and forestry agencies to learn about wildfire prevention efforts and the role of neighborhood organizations in these efforts. The interviews showed tremendous diversity in neighborhood organization membership structure, functions, dues and budget, and wildfire preparedness activities offered. These characteristics were examined to identify possible relationships with the willingness of neighborhood organizations' to participate in wildfire preparedness activities.

Key Findings

We interviewed individuals in six communities that had WUI neighborhoods at risk of wildfire, a history of fire within the region, and a history of wildfire education and outreach efforts. The study communities included Anchorage, Alaska; Bastrop, Texas; Berkeley Township, New Jersey; Colorado Springs, Colorado; Ormond Beach/Volusia County, Florida; and Spearfish, South Dakota. Findings from the interviews highlight several areas that may help resource managers work with neighborhood organizations and develop effective programs within their jurisdictions.

- **Working with neighborhood organizations can be one of the best ways for resource managers to reach residents and extend agency outreach.**
- **Neighborhood organizations can help model fire mitigation behavior for community members.**
- **There is no one-size-fits-all neighborhood organization; instead these organizations fit the character of the people and the place. Managers need to adjust their approach to fit the local organization's characteristics.**
- **Wildfire preparedness activities cannot be explained by an organization's resources, membership, or budget.**
- **Leaders who are networked with other groups may be the key to increased preparedness activities. Identifying active neighborhood leaders and providing opportunities for recognition can greatly increase the effectiveness of outreach efforts.**
- **Managers can support local fire mitigation efforts by providing resources and technical assistance to neighborhood organizations.**
- **Open communication facilitates the process. Managers need to work to create, maintain, and support good lines of communication.**

Detailed Findings

Working with neighborhood organizations can be one of the best ways for resource managers to reach residents and extend agency outreach efforts. Neighborhood leaders mentioned many preparedness activities, but educating homeowners and creating efficiencies by supporting group projects were the major activities undertaken. Basic wildfire preparedness activities conducted by neighborhood organizations ranged from disseminating information in newsletters and Web sites to having fire department and Firewise representatives speak or show a video at meetings. More comprehensive programs included activities such as holding chipping/mulching events, working on common areas to reduce wildfire risk, and scheduling special events to educate residents, e.g., fairs, picnics, and school programs. In several cases, communities provided cost-sharing grants or equipment to the neighborhood organizations to facilitate the chipping/mulching events and common area cleanups.

Other types of advanced preparedness activities included creating demonstration areas around homes, assisting residents with evacuation planning, holding workdays to assist elderly and disabled residents, and forming a committee to address wildfire preparedness. In some neighborhood organizations, leaders reviewed covenants and regulations to determine if they contributed to wildfire risk. They worked to make changes either in their own covenants or at the community level in the areas of roofing material, vegetation clearing, and slash burning. Two neighborhood organizations enforced their covenants to require noncomplying homeowners to manage overgrown vegetation and replace wood-shake roofs.

Some neighborhood organizations contacted government agencies about reducing wildfire risk on adjacent lands through prescribed burning or mechanical vegetation removal. Bob Bendlin and Jim Mozo, officers with the 200-home Plantation Pines Homeowners Association (Volusia County, Florida) have established strong relationships with Ormond Beach and Volusia County fire departments and The Nature Conservancy. In addition to attending local government-sponsored Firewise training workshops and meetings, the two men helped coordinate a prescribed burn on adjacent public lands that included outreach to neighborhood residents. Said Bendlin, "We felt it was important to educate residents so they understood why we were doing the burn and what effects they could expect from it. Reactions from residents have been favorable for the most part. The one person who complained moved." Bendlin and Mozo also convinced residents in the rural subdivision to pay for the installation of horizontal hydrants to improve firefighting capabilities. Recently, they worked with fellow residents to convince the fire department to locate a new station next to their subdivision on a donated parcel of land.

Neighborhood organizations can help model fire mitigation behavior for community members. The type and frequency of social events offered by neighborhood organizations do not suggest a strong relationship with their proclivity to undertake wildfire preparedness activities. At the same time, social networks do seem to play a role in wildfire preparedness. Several of the interviewees from more active neighborhood organizations commented that residents who see neighbors remove vegetation or take other preparedness actions are often inspired to do the same. The Texas Forest Service and Bastrop Volunteer Fire Department worked with Pine Forest and Tahitian Village neighborhood associations to organize two mulch festivals for residents. According to Mike Norman, Chief of the Bastrop Volunteer Fire Department, "During the second festival, chippers went around to peoples' properties, ground the vegetative debris, and left the chips for homeowner use. The chipping was supposed to be done in two weekends. Residents saw their neighbors clearing vegetation and decided they needed to do the same. It ended up taking 2 months to do all the chipping."

In Hunters Ridge (Volusia County, Florida), board members and association staff worked hard to reduce their wildfire risk in several common areas located within the 400-home subdivision. Ken Duvall, president of the homeowners association, explained, "We trimmed trees, cleared brush, and removed all highly flammable types of vegetation such as palmettos, replacing it with less flammable species. In addition to reducing wildfire risk, we want to set a good example for residents since we are encouraging them to do the same." The association made the common area cleanup a priority and was able to fund cleanup and planting costs within their budget.

There is no one-size-fits-all neighborhood organization that is best to work with; instead these organizations fit the character of the people and the place. Characteristics such as size, membership type, and budgets do not matter in selecting neighborhood organizations to work with. Managers need to adjust their approach to fit the local organization's characteristics. They need to talk to leaders to determine what priority wildfire preparedness may have and to identify possible barriers to adopting preparedness behaviors. Learning about each neighborhood organization's structure, communication system, demographics, and social norms will be helpful in assessing resource and information needs and developing effective messages.

Neighborhood organizations in this study include homeowner associations, community councils, volunteer fire departments, and neighborhood block clubs. The number of homes in each neighborhood ranges from 15 to more than 1,000. Membership types include mandatory, voluntary, or mandatory with a grandfather clause for residents that pre-dated formation of the association. Membership dues for these organizations range from $25 to more than $1,000 per year. Some neighborhood organizations secure additional funds through voluntary assessments, fund-raising events, and grants.

Annual operating budgets vary considerably depending on the services provided. Neighborhood organizations that provide infrastructure elements such as road building and maintenance, water systems, and fire protection tend to have larger budgets and typically hire part- or full-time staff. Other functions performed by neighborhood organizations include reviewing and controlling architecture/landscape actions, enforcing codes and covenants, providing social opportunities, operating recreational facilities, solving neighborhood problems, educating homeowners about important issues, and representing the neighborhood in the larger community.

Activities common to almost all neighborhood organizations include holding general membership and board meetings, organizing social events, and communicating with other entities. Frequent interactions have occurred with government agencies, fire departments, and umbrella organizations (e.g., coalition of homeowner associations) on issues such as zoning, subdivision infrastructure, wildfire preparedness, neighborhood schools, and adjacent developments. Several of the neighborhood organizations have some type of internal neighborhood communication system. According to Bill Bomberg, president, the Mountain Plains II Homeowner Association (Spearfish, South Dakota) is especially effective at communicating with its members:

> *We probably communicate more than anyone, we try to keep information out in front of people. We have up to 75 percent of the homeowners' e-mail addresses so if anything needs immediate attention, we'll go ahead and put out an e-mail. If the information can wait, then we put it out in a newsletter every 2 months. If it's something important, we have a*

calling tree. We've used it for rationing water when levels in the tank were low and could use it if we're threatened by fire.

Wildfire preparedness activities cannot be explained by an organization's resources, membership, or budget. Our review suggests that the size, membership type, and budget of a neighborhood organization do not have a significant effect on the type and number of wildfire preparedness activities conducted. The more active groups vary widely in their structures, ranging from one organization with less than 50 voluntary members run by volunteer officers with a small budget to another with several hundred mandatory members run by paid staff with a more substantial budget.

Neighborhood organizations that provide infrastructure services tend to be among those more actively involved in wildfire preparedness. It is possible that the officers and staff of those organizations view wildfire preparedness as similar to a service such as fire protection. The Circle D Civic Association (Bastrop, Texas) encompasses 460 homes and provides road maintenance and paving, architectural review and control, maintenance of two common areas, and neighborhood representation on issues such as endangered species and unexploded Army ordinance. Tammy Pickering, office manager of the Circle D Civic Association, explained,

Photo credit: Holly Johnson Shiralipour

Board members cleaned up vegetation in common areas and around their Florida clubhouse to reduce wildfire risk and demonstrate a firewise landscape to the community.

The association is closely intertwined with the volunteer fire department. We lease the fire station to the VFD for $1 per year and contributed an addition on the building and money for trucks. Ten dollars of every assessment goes to the fire department. We work closely with the VFD to help homeowners with wildfire mitigation and give fire department officials time at every board meeting.

Leaders who are networked with other groups may be the key to increased preparedness activities. Identifying active neighborhood leaders and providing opportunities for recognition can greatly increase the effectiveness of outreach. Identifying neighborhood organization leaders who will champion the cause of wildfire preparedness is an important place to start. The most obvious leaders are officers or committee members. Other potential leaders include residents with a personal interest in the issue such as environmentalists (e.g., members of The Nature Conservancy or Audubon), people with a related occupation (e.g., firefighters), or residents with previous wildfire or home fire experiences. Managers can obtain contact information for neighborhood leaders from property appraisers, planning and zoning departments, fire departments, and areawide councils of neighborhood associations. If neighborhood organization officers do not appear to be the most appropriate contacts for working on wildfire preparedness, they may be helpful in identifying residents who would be willing contacts.

Bill Robertson and Richard Randall, officers with Top of Skyway Homeowner Association (Colorado Springs, Colorado), are examples of neighborhood leaders that act as champions. A wildfire risk map produced by the Colorado Springs Fire Department helped them realize their neighborhood was at high risk of wildfire. "We want to be responsible homeowners and were naturally drawn to the topic of wildfire preparedness," Robertson said. "We put our civic hats on and decided to get our association involved," Randall added. The two worked frequently with the Colorado Springs Fire Department to organize a neighborhood meeting that featured a fire department speaker and traveling Firewise trailer, set up a home demonstration site to show vegetation removal, and obtained material for their association newsletter. They also organized a cleanup. A neighborhood survey they conducted showed a very positive reaction to the Firewise initiative.

Recognition programs for neighborhood leaders who effectively champion wildfire preparedness increase local awareness of wildfire preparedness actions, provide positive feedback to participants, and help to establish a social norm of increased wildfire preparedness. The Colorado Springs Fire Department started a program to recognize neighborhood leaders that promoted wildfire preparedness in their subdivisions. The neighborhood champions receive awards and media recognition for their efforts. Kathy Prudhomme with the Colorado Springs Fire Department noted, "The recognition program has been very well received and seems to help motivate other neighborhood leaders to act as champions." Another opportunity for recognition is the national Firewise program. Neighborhoods can elect to participate in the program and if they meet the criteria of the program, they will be certified as Firewise communities (www.firewise.org).

Managers can support local fire mitigation by providing resources and technical assistance to neighborhood organizations.

A number of helpful wildfire preparedness resources and ideas for technical assistance identified during the interviews are useful to consider when developing a neighborhood outreach program. Many of the government agencies and fire departments in the study made staff available to assist neighborhoods with presentations at meetings, hazard assessments and evaluations, and evacuation planning. These agencies also helped neighborhoods plan vegetation removal/cleanup events (sometimes offering incentive grants), conduct demonstration sites at neighborhood homes, and review covenants and regulations pertaining to wildfire preparedness. Resources provided to neighborhood organizations include articles for their newsletters; wildfire preparedness checklists or assessment tools; videos; and brochures, magnets, posters, and demonstration site signs.

Open communication facilitates the process. Managers need to work to create, maintain, and support good lines of communication.

Study results suggest that creating and maintaining good communication with neighborhood leaders helps foster more wildfire preparedness activity at the neighborhood level. Contacting neighborhood organization leaders several times a year will engage them and encourage them to use available resources.

The degree of internal and external communication occurring within neighborhood organizations also appears to have a bearing on how active these organizations are in conducting wildfire preparedness activities. Neighborhood organization leaders who communicate regularly with both members and outside entities act as champions for issues such as wildfire preparedness. They use personal conversations, phone trees, e-mail messages, Web sites, and newsletters to create awareness, educate members, and galvanize them to take action. These individuals readily seek outside expert assistance from fire departments, government agencies, and others to enhance their efforts.

Methods

We selected six communities that had WUI neighborhoods at risk of wildfire from nearby forested wildlands (public or private) and a history of fire within the region. In addition, State forestry agencies and fire departments that serve the six study sites had implemented wildfire education and outreach with a number of the local neighborhoods. The study communities include Anchorage, Alaska; Bastrop, Texas; Berkeley Township, New Jersey; Colorado Springs, Colorado; Ormond Beach/Volusia County, Florida; and Spearfish, South Dakota. Within each of the six communities, four to six geographically defined neighborhoods were identified with assistance from local fire department personnel and State forestry agency staff. Each neighborhood is located in the WUI around a community. Some have formal, functional neighborhood organizations and some do not. The neighborhoods also differ in the amount of wildfire prevention education they received, ranging from none to considerable.

Interviews were held from October 2003 to May 2004. Across the six communities, 27 interviews were carried out with officers and staff from neighborhood organizations. Three interviews were conducted with volunteer fire departments that effectively functioned as neighborhood organizations. An additional 14 interviews were held with fire department personnel and government agency staff.

One interview guide was prepared for neighborhood organization officials and staff with qualitative and quantitative questions. The first section contained qualitative questions designed to elicit open-ended responses. Questions were asked about:

- History and activities of the organization
- Neighborhood layout, lot sizes, average home prices, and number of developers
- Fire risk to the neighborhood including fuel treatments
- Fire preparedness activities specific to the neighborhood
- Social capital within the neighborhood; "Social capital refers to those stocks of social trust, norms, and networks that people can draw upon to solve common problems" (Sirianni and Friedland 2005)
- Interactions with government agencies.

The other section included quantitative questions about the structure of the organization and neighborhood demographics: membership requirements, meetings and meeting attendance, officers, elections, planning efforts, operating budget, staff, newsletters, active block clubs or crime watch groups, number of homes and lots in the neighborhood, and age of the development.

The second guide was developed for interviews with fire department personnel and agency officials. It contained questions about the types of actions taken to promote wildfire preparedness within the general community and specifically with the residents of the study neighborhoods, fuels treatments carried out near the study neighborhoods, and general background data on fire departments serving the area. Additional questions were asked about study neighborhoods without an association to determine the approximate number of homes and undeveloped lots present and a description of the development.

Literature Review—Neighborhood Organizations as Outreach Partners

The structure of neighborhood organizations encourages resident participation in a range of activities, which suggests that neighborhood organizations may be one of the more effective ways to engage people in adopting wildfire preparedness actions. Examples of organizational structures include homeowner associations, neighborhood councils, and volunteer fire departments. Using established neighborhood organizations potentially offer several advantages over forming new groups or working with service and church-based organizations, social groups, and sport clubs. This finding has been recognized by a growing number of government agencies, nonprofit organizations, and fire departments working with neighborhoods and neighborhood organizations to promote wildfire preparedness (Boura 1998, McGee and Russell 2003, NWCG 1998).

Neighborhood organizations represent a physical, social, and political entity. Each neighborhood is a limited territory within a larger urban area where people inhabit dwellings and interact socially. As a territory, a neighborhood is a physical place that others can visualize in terms of structures, streets, and natural features. To residents, their neighborhood has a distinct appearance that they use to differentiate themselves from other neighborhoods (Hallman 1984). Residents vary considerably in perceptions of fire mitigation measures such as creating defensible space (Nelson *et al*. 2004, 2005; Vogt *et al*. 2003). How they view their neighborhood may influence their perceptions of these measures. At the same time, having the same physical territory in common can facilitate participatory opportunities such as organizing a cleanup mulching event or a work day to clean out common areas, or addressing a neighborhood concern such as insufficient evacuation routes.

In addition to being an objective reality, a neighborhood is a subjective entity. Informal neighboring activities, travel patterns, status and bonds of race, religion, or social class are among the factors that shape how each resident perceives his or her personal neighborhood identity (Hallman 1984). Residents may have strong social ties, particularly if they live in a neighborhood populated by strong racial, ethnic, or socioeconomic groups. Neighborhoods may also contain residents who hold conflicting values over various issues (Hallman 1984, Perkins *et al.* 1996, Sampson *et al*. 2001). Being aware of this information can help community officials and fire protection departments tailor their messages to each neighborhood (McKenzie-Mohr and Smith 1999, Mileti *et al.* 2004, Tierny *et al*. 2001). These characteristics will also come into play as neighborhood organizations address the wildfire threat in ways that meet their specific needs.

Because many neighborhoods are relatively homogeneous, most of their residents have similar behavioral norms and values. These might include common expectations of house upkeep, yard care, use of yards, level and timing of noise, and acceptability in terms of displaying wealth and other status symbols (Hallman 1984). Much of the process of communicating neighborhood values and norms occurs informally within the family, neighbor-to-neighbor, or through peer groups (Hallman 1984, Sampson *et al.* 2001). The communication process helps residents confirm information they receive from outside sources. These values and norms influence behavior as residents see neighbors creating defensible space and doing other wildfire preparedness activities (McKenzie-Mohr and Smith 1999, Rogers 1995). Neighborhoods also have more formal channels of communication including newsletters, newspapers, posters, e-mail listservs, and phone trees. The informal and formal communications process forms the nerve system of the neighborhood community. This communication process can help foster acceptance of responsibility for reducing the wildfire threat because residents will be more likely to personalize a message when they receive it via multiple channels and see others taking action (Mileti and Fitzpatrick 1992, Milieti *et al*. 2004, Rohrmann 1999).

Neighborhood organizations are a political entity. Governance can range from informal self-governance over a few aspects of neighborhood life to full-scale self-governance. The neighborhood can be a base of political action for dealing with local governments or function as an interest/advocacy group for wider representation in those domains (Berry *et al.* 1993, Hallman 1984, Thomson 2001). The issues they tackle often range widely. Regular or annual meetings can be used to provide wildfire education to residents or to discuss how the members of the organization want to address wildfire preparedness (NWCG 2004). Communities may find it easier to approach and work with neighborhood organizations on wildfire preparedness issues because they have previously established relationships (Kruger *et al.* 2003, Tierny *et al*. 2001). Conversely, residents may find the ties useful for obtaining information and assistance with activities such as mulching events and common area cleanup projects. Residents look to their neighborhood to provide protection of values, properties, and personal safety, which may be accomplished through homeowner associations, volunteer fire departments, crime watch groups, or hired security patrols (Hallman 2004). Some neighborhoods are involved in providing services such as overseeing home construction oversight and constructing and maintaining open spaces, facilities, and roads (Berry *et al*. 1993, Hallman 1984, Thomson 2001). In some cases, neighborhood organizations may have restrictive covenants that prevent or discourage wildfire preparedness activities such as creating defensible space. The neighborhood organization can work alone or with the community to make regulations more favorable (NWCG 2004).

Acknowledgments

Funding for this research project was provided by the USDA Forest Service, North Central Research Station; the University of Florida IFAS Extension; and the University of Minnesota Experiment Station.

References

Berry, J.M.; Portney, K.E.; Thomson, K. 1993. The rebirth of urban democracy. Washington, DC: The Brookings Institute. 326 p.

Boura, J. 1998. Community fireguard: creating partnerships with the community. CFA Occas. Pap. 2. Mt. Waverly, VIC Australia: CFA Community Safety Directorate: 16.

Hallman, H. 1984. Neighborhoods: their place in urban life. Beverly Hills, CA: Sage Publications, Inc. 320 p.

Kruger, L.E.; Agrawal, S.; Monroe, M.; *et al*. 2003. Keys to community preparedness for wildfire. In: Jakes, Pamela J., comp. Homeowners, communities, and wildfire: science findings from the National Fire Plan: proceedings of the 9th International symposium on society and natural resource management; 2002 June 2-5; Bloomington, IN. Gen. Tech. Rep. NC-231. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 10-17.

McGee, T.K.; Russell, S. 2003. It's just a natural way of life...an investigation of wildfire preparedness in rural Australia. Environmental Hazards. 5: 1-12.

McKenzie-Mohr, D.; Smith, W. 1999. Fostering sustainable behavior: an introduction to community based social marketing (Education for sustainability series). Gabriola Island, BC, Canada: New Society Publishers. 176 p.

Mileti, D.S.; Fitzpatrick, C. 1992. Causal sequence of risk communication in the Parkfield Earthquake Prediction Experiment. Risk Analysis. 12(3): 393-400.

Mileti, D.S.; Nathe, S.; Gori, P.; *et al.* 2004. Public hazards communication and education: the state of the art. Natural Hazards Informer. Boulder, CO: National Hazards Research and Applications Information Center, University of Colorado-Boulder: 13.

Nelson, K.C.; Monroe, M.C.; Fingerman Johnson, J.; Bowers, A. 2004. Living with fire: homeowner assessment of landscape values and defensible space in Minnesota and Florida, U.S.A. International Journal of Wildland Fire. 13(4): 413-425.

Nelson, K.C.; Monroe, M.C.; Fingerman Johnson, J.; Bowers, A. 2005. The look of the land: homeowner values, actions, and defensible space landscapes in Minnesota and Florida. Society and Natural Resources. 18(4): 321-336.

National Wildfire Coordinating Group (NWCG). 1998. Wildfire prevention strategies. PMS 455/NFES 1572. [City, State unknown]: U.S. Department of Agriculture, U.S. Department of the Interior: National Association of State Foresters: National Wildfire Coordinating Group: 118.

National Wildfire Coordinating Group (NWCG). 2004. FIREWISE: making sensible choices in the wildland/urban interface. Quincy, MA: National Wildland/Urban Interface Fire Program.

Perkins, D.; Brown, B.; Taylor, R. 1996. The ecology of empowerment: predicting participation in community organizations. Journal of Social Issues. 52(1): 85-111.

Rogers, E. 1995. Diffusion of innovations. 4th ed. New York, NY: The Free Press. 518 p.

Rohrmann, B. 1999. Community-based fire preparedness programmes: an empirical evaluation. Australasian Journal of Disaster and Trauma Studies. 1999-1: 23.

Sampson, R.; Squires, G.; Zhou, M. 2001. How neighborhoods matter: the value of investing at the local level. Washington, DC: American Sociological Association. 61 p.

Sirianni C.; Friedland L. 2005. Social capital definition: civic dictionary. CPN-Civic Practices Network Web site. Waltham, MA: Brandeis University http://www.cpn.org/tools/dictionary/capital.html September 18, 2005.

Thomson, K. 2001. From neighborhood to nation: the democratic foundations of civil society. Hanover, NH: University Press of New England. 195 p.

Tierny, K.J.; Lindell, M.K.; Perry, R.W. 2001. Facing the unexpected: disaster preparedness and response in the United States. Washington, DC: John Henry Press. 306 p.

Vogt, C.; Winter, G.; Fried, J. 2003. Anticedents to attitudes toward prescribed burning, mechanical thinning, and defensible space fuel reduction techniques. In: Jakes, Pamela J., comp. Homeowners, communities, and wildfire: science findings from the National Fire Plan: proceedings of the 9th International symposium on society and natural resource management; 2002 June 2-5; Bloomington, IN. Gen. Tech. Rep. NC-231. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 74-83.

CHAPTER 6—URBAN INTERFACE

CONTENTS

SAFETY FIRST—NO EXCEPTIONS

WILDLAND /URBAN INTERFACE "WATCH OUT" SITUATIONS

"REFERENCE FIRELINE HANDBOOK
CHAPTER 1, PAGE 9"

STRUCTURE TRIAGE GUIDELINES

Firefighter safety is the <u>primary consideration</u> when evaluating whether a structure can be protected. There are three categories of structures:

- Those that are <u>not threatened.</u>
- Those that are <u>threatened</u> and have the potential of being saved.
- Those that are <u>not able to be saved</u> and too dangerous to protect.

Factors to consider during structure triage:

- FIREFIGHTER SAFETY
- Safety Zone Availability (is there time to prepare a safety zone?)
- Proximity of the fuels and predicted flame length to structure (no defensible space).
- Position on slope relative to fire spread.
- Fire behavior and intensity (the greater the intensity, the wider the defensible space needed).

- Flammability of roof and siding (wood roof and siding, vinyl siding**,** along with inadequate defensible space may make structure impossible to protect).

- Timing and available resources (not having time to position resources or lack of resources to protect structure).

An attempt to save a structure may be unsuccessful or too dangerous if:

- There is no safety zone and refuge available.

- There is no place to park engine safely.

- Fire is making a sustained run and there is little or no clearance.

- Fire behavior is extreme: spot fires are numerous and out pacing control.

- Water supply will not last as long as the threat.

- Fire's intensity dictates you leave the area NOW.

- Roof is more that ¼ involved.

- Fire inside structure, windows broken, and windy conditions.

- You cannot safely remain at the structure and your escape route could become not longer safe to use.

<u>If a structure becomes well involved, leave it and move on to one that can be saved**.**</u>

STRUCTURE ASSESSMENT CHECKLIST

Address/Property Name

- Numerical street address, ranch name, etc.
- Number of residents on site

Road Access

- Road surface (paved, gravel, unimproved, dirt)
- Adequate width, vegetation clearance and safety zones along road
- Undercarriage problems (4x4 access only)
- Turnouts and turnarounds
- Bridges (load limits)
- Stream crossings (approach angle, crossing depth and surface)
- Terrain (road slope, location on slope-near chimneys, saddles, canyon bottom)
- Grade (greater than 15%)

Structure/Building

- Single residence or multi complex, out building (barn, storage)
- Does building have unknown or hazardous materials?
- Exterior walls (stucco or other non-combustible, wood frame, vinyl, wood shake)
- Large unprotected windows facing heat source
- Proximity of any aboveground fuel tanks (LPG, propane, etc.)
- Roof material (wood shake, asphalt, non-combustible)
- Eaves (covered with little overhang, exposed with large overhang)
- Other features (wood deck, wood patio cover and furniture, wood fencing)

Clearances/Exposures/Defensible Space

- Structure location (narrow ridge, canyon, mid-slope, chimney)
- Adequate clearance around structure-minimum of 100' (steeper the slope the more clearance required)
- Surrounding fuels (larger, denser the fuels, the more clearance required)

- Flammable fuels (trees, ladder fuel, shrubs) adjacent to structure (is there time for removing these fuels?)

- Other combustibles near structure (wood piles, furniture, fuel tanks)

- Is there adequate clearance around fuel tank?

- Power lines or transformers (DO NOT park under lines)

Hazardous Materials

- Chemicals (Look for DOT/NFPA/UN symbols)

- Pesticides and herbicides

- Petroleum products

- Paint products

Water Sources

- Hydrant/standpipe (When connecting with hydrant, be aware of flow rate and gpm output, size and venting capability of engine or water tender may not be able to handle hydrants with high flow and gpm rates.)

- Storage tank

- Swimming pool

- Hot tub

- Fish pond
- Irrigation ditch

Evacuation

- Is safe evacuation possible? (Identify safe refuge for those who cannot be evacuated.)
- Coordinate with on-scene law enforcement and emergency services personnel.

Estimated Resources for Protection

- Number(s) and type(s) of engines, water tenders, crews, dozers (General Guidelines: one engine per structure, one additional engine for every four structures to be used as "back-up" and for patrol. For structures that are close together (50' or less), one engine may be adequate to protect two structures.
- Type and number of aircraft available.

STRUCTURE PROTECTION GUIDELINES

DO NOT enter a structure unless you are trained, equipped, and authorized. If safe, a structure can be used as refuge. Firefighter safety and survival is the number one priority. Supervisors must keep in close communication with those you supervise and adjoining forces in the area.

Equipment Placement

- Identify escape routes and safety zones and make them known to all crew members.
- ALWAYS STAY MOBILE and wear all of your PPE.
- Back equipment in for quick escape.
- Mark entrance to long driveways to show that protection is in place (*very important* when structure can not be seen from road).
    - Multiple ribbons at end of drive on street
    - Ribbon/flagging across drive entrance
    - Sign
    - Other pre-determined signal
- Park in a cleared area (watch for overhead hazards).
- Protect your equipment (park behind structure, placing structure between equipment and fire front; be aware of spot fires occurring behind you).
- Watch for hazards (drop-offs, pot holes, above-ground fuel storage, chemicals, septic tanks).

- Keep egress route clear:

  - park extra equipment on street
  - keep hose off driveway

- Have an engine/crew protection line charged and readily available.

- DO NOT make long hose lays.

- Try to keep sight contact with all crewmembers.

Water Use Guidelines

- Keep at least 100 gallons of water reserve in your tank.

- Top off tank at every opportunity; use garden hose.

- Draft from swimming pool, hot tub, and fishpond.

- STAY MOBILE. Do not hook up to hydrant except to refill tank. (Hydrant may not always work if system is electric powered and power is lost in area.)

- CONSERVE WATER, avoid wetting down an area.

- Apply water only if it controls fire spread or significantly reduces heating of structure being protected.

- Keep fire out of the heavier fuels.
- Extinguish fire at its lowest intensity, not when it is flaring up.
- Knock down fire in the lighter fuels.
- Have enough water to last duration of main heat wave and to protect crew.

Class A Foam Use Guidelines

- Direct Attack - apply to base of flame.
- Indirect Attack - lay out wet line and burn out.
- Apply to structure (roof and siding) 10-15 minutes before fire arrives.

Preparing Structure

- Determine if residents are home (legal responsibility for evacuation lies with law enforcement). If residents remain on-scene, advise them to use structure if it's safe to do so as refuge when fire arrives.
- For roof access, place owner's ladder at a corner of structure on side with least fire threat and away from power drop.
- Clean roof of leaves, needles, and any other combustible materials.
- Cover vents and air conditioning unit on roof.

- Remove and scatter away from structure:

  - over-hanging limbs.

  - ground/ladder fuels to prevent fire from moving into the crowns.

  - wooden fences and wood piles near structure.

- Clear area around above-ground fuel tank, shutting off tank.

- Place combustible outside furniture inside structure.

- Close windows and doors, including garage, leaving unlocked. AS A LAST RESORT, YOU MAY NEED TO USE STRUCTURE AS REFUGE.

- Have garden hose(s) charged and place strategically around structure for immediate use.