



**Pacific Southwest
Research Station**

General Technical Report
PSW-GTR- 173

April 5-9, 1999

San Diego, California

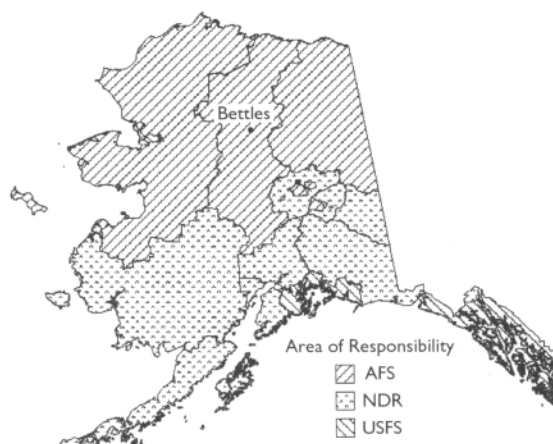
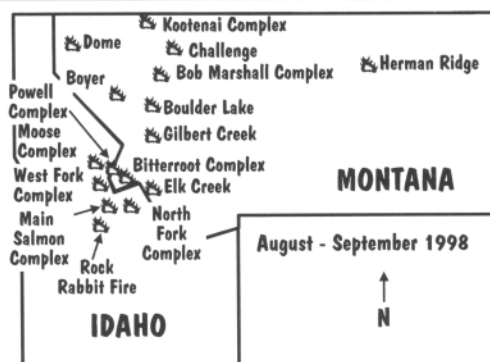


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GD3	PV52	Dayton Prev Tech	32935	X
GD4	PVREC1	Rec. Patrolman	70	
GD5	SJ071	Smokeyjumpers, stk 1	70179	X
GD6	SJ072	Smokeyjumpers, stk 2	38156	X
GD7	SJ073	Smokeyjumpers, stk 3	17242	X
GD8	SJ074	Smokeyjumpers, stk 4	17242	X
GD9	SJ075	Smokeyjumpers, stk 5	17242	X
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Abstract

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These proceedings summarize the results of a symposium designed to address current issues of agencies with wildland fire protection responsibility at the Federal and State levels. The topics discussed at the symposium include fire economics, planning, and policy on wildfire and prescribed fire. Representatives from several international organizations presented the experiences in their countries on the same issues. Forty-five invited papers and 12 posters were presented at the symposium that described the issues and presented state-of-the-art techniques to address technical issues on fire economics, planning, and policy currently facing land and fire managers.

Retrieval Terms: fire economics, fire simulation models, prescribed fire, resource valuation, strategic fire planning, wildfire costs, wildland fire policy

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Acknowledgments

Many people and institutions contributed to the success of this symposium. It is difficult to list them all, but the following persons and groups deserve special recognition. First, we thank our sponsors, in particular the USDA Forest Service's Pacific Southwest Research Station, and Aviation and Fire Management staff, Washington Office, for their financial support. We also thank the Colorado State University Division of Educational Outreach for processing registrations; the International Association of Wildland Fire for providing mailing lists and advertising the activity; and the Society of American Foresters for providing continuing education credits for attending the symposium and providing advertising for the activity. Thanks to all authors during the long process of manuscript preparation, editing, and production. There are four individuals deserving special recognition: Nikki Omi for her untiring work securing the proper venue for the activity and making sure that everything went smoothly, Yang Hang for the wonderful job he did developing the symposium website, Lola Thomas for revising manuscripts once they were edited, and special thanks to Laurie Dunn for her superb job in editing all of the manuscripts for this proceedings.

Proceedings of the Symposium on Fire Economics, Planning, and Policy: Bottom Lines

April 5-9, 1999 San Diego, California

Armando González-Cabán Philip N. Omi
Technical Coordinators

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Preface

The first "Symposium on Fire Economics, Policy, and Planning: Bottom Lines" convened in San Diego, California, April 5-9, 1999. This symposium represented more than 3 years of cumulative planning and organizational efforts, although the theme that brought researchers and managers together has been taking place throughout the past century in forests, wildland areas, and suburban locales all over the world. Fire moving across pristine landscapes during the burning season is a common image to the public, as well as the drama of tired and courageous firefighters, and the heartbreak of those who have lost homes and loved ones. Fire, whether wild or prescribed, is frequently covered by the media.

Yet, behind the scenes, other stories have rarely been told or seem to merit less attention, perhaps because economics, policy, and planning discussions are not as spectacular as a flaming hillside. Relatively little attention is focused on the high cost of managing wildfires or ensuring that the best decisions are implemented in managing fire incidents. The public seemingly would prefer to see an airtanker flying overhead rather than worry about the costs and choices in managing fires.

The study of fire economics, or writing policy and plans, can be tedious. Some of the best minds in forestry have been unsuccessful in attempting to solve problems in related subject areas. Furthermore, growing numbers would acknowledge that unquestioned public support for fire management decisions is a luxury of the past. As we approach the year 2000, we can look forward to a public that demands greater accountability for fire management actions and expenditures.

The subject of this symposium was both encouraging and timely. Eighty-four national and international experts contributed to the dialogue at the symposium by presenting more than 40 papers and 11 posters. These contributions should be viewed as a starting point for a discussion that is both overdue and in need of constant evaluation. As with any initial effort, the topics covered often raised as many questions as answers. However, we feel fortunate that some of the world's best minds gathered to initiate this important dialogue. Furthermore, as these published proceedings attest, the dialogue must continue in the future.

This symposium was organized around several themes. The first theme was the need to exchange information on the economic impacts of fire management. Because the majority of fire management activities are carried out by public land management agencies, we organized a panel with representatives from some of the preeminent fire management agencies in North America. This introduction was followed by two sessions covering the scope of large fires and fire management costs.

Planning for fire management comprised a second major theme for the symposium. In recognition that no single perspective works for all situations, we assembled speakers from a variety of nations, organizations, and backgrounds--all with a common interest in sharing experiences and concepts involved with planning fire management expenditures, policy evolution, and valuation schemes. This discussion continued through five general sessions, stimulating interesting questions and after-hours discussion.

A third major theme of this symposium focused on contemporary interest in fuels management, prescribed fire, and fire restoration. With recent policy revisions and current projections, we can anticipate increased interest and activity directed toward treating fuels in a variety of ecosystems. Thus, this symposium represents one of the first forums for discussing the economic and policy implications of the recent re-direction of agency priorities from fire suppression in favor of preparedness activities.

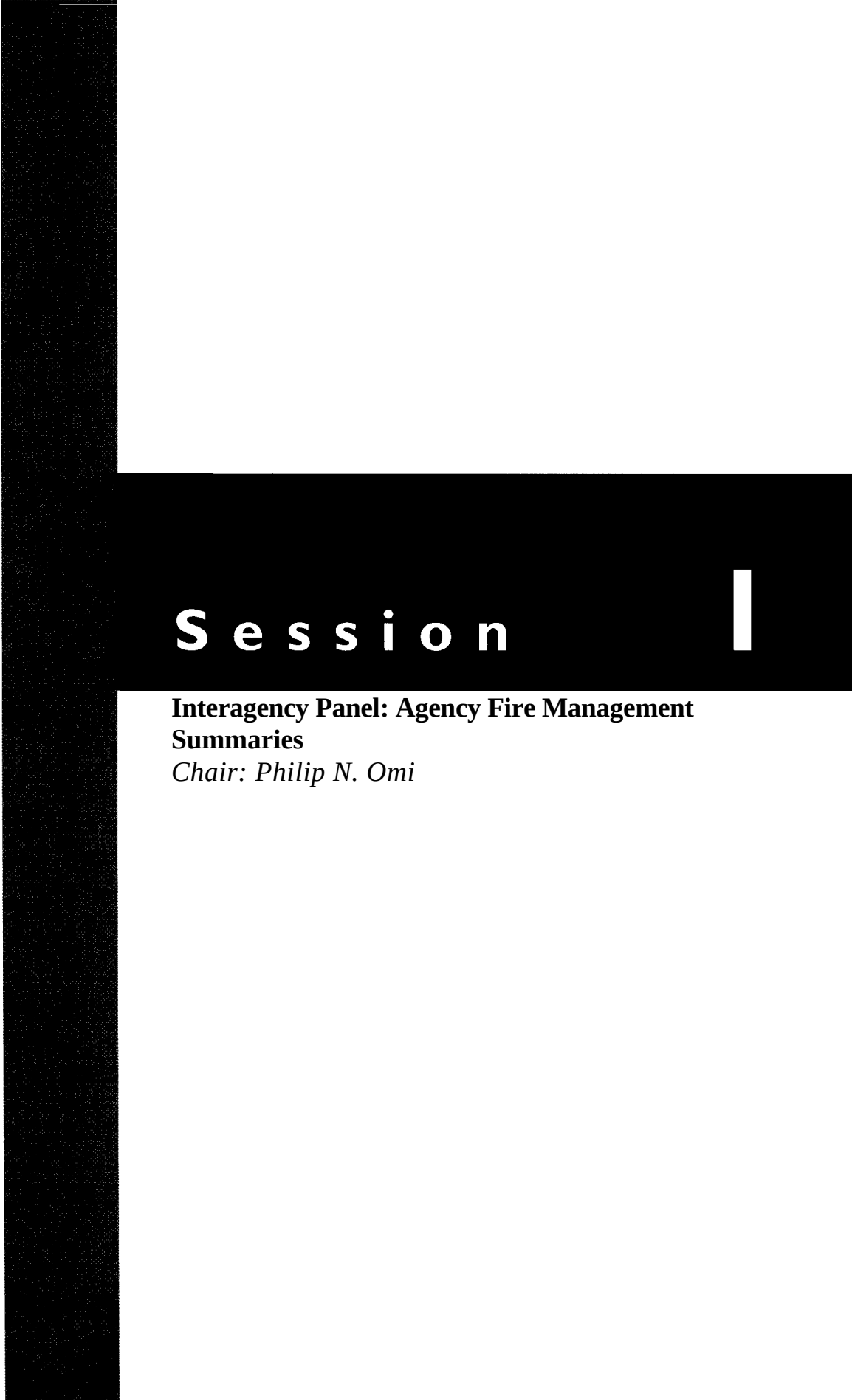
Finally, we culminated our symposium with presentations on case studies in reducing fire management costs. We recognize that fire management involves choices about allocation of scarce resources and that sometimes decisions can

lead to undesirable consequences. We need to celebrate and publicize efforts that have resulted in more efficient resource allocation decisions.

By the end of the week, participants generally recognized that we had been involved in a very special exchange of ideas and thoughts for the future. The challenge is to extend the momentum generated from this symposium into the future to improve fire management of our precious wildlands.

The success of the symposium was a result of the effort of many individuals and groups. Special acknowledgments need to be extended to sponsors, including the USDA Forest Service (Washington Office and Pacific Southwest Research Station), Colorado State University (Division of Educational Outreach), the International Association of Wildland Fire, and the Society of American Foresters.

Armando González-Cabán
Philip N. Omi
Technical Coordinators



Session

**Interagency Panel: Agency Fire Management
Summaries**

Chair: Philip N. Omi

California Department of Forestry and Fire Protection: Fire Management Summary¹

Wayne Mitchell²

Abstract

The California Department of Forestry and Fire Protection (CDF) is a full service wildland, rural, and urban fire department. CDF responds to 6,600 fires during an average year and contains about 95 percent of the fires at less than 10 acres. About 55 percent of CDF's \$452 million annual budget is used for wildland fire protection, with the remainder used for resource management, Fire Marshal operations, local government rural and urban fire protection, and administration. CDF fire managers supervise 17,700 professional, seasonal, volunteer, and inmate firefighters that operate a full spectrum of wildland fire fighting equipment.

Responsibility and Jurisdiction

In 1905, the California legislature established the State Board of Forestry (later renamed the State Board of Forestry and Fire Protection). The board was given a mandate to provide protection to the forest and water resources of the state and to set policy for the California Department of Forestry and Fire Protection (CDF) in the administration of protection programs. The legislature also charged the Board of Forestry and Fire Protection with identifying those California lands where the fiscal responsibility for wildland fire protection is primarily the responsibility of the state (State Responsibility Area or SRA). The board has identified about one-third of California's 100 million acres as SRA. About one-third of the land is the responsibility of the Federal government, and the remaining one-third is local government responsibility, either incorporated cities, cultivated farmland, or desert.

Federal land management policies of the last century (1800's) were designed to settle the western frontier. Railroads were deeded every other square mile of land. Mining claims became scattered across much of the landscape. Parks and reserves were set aside for future generations, and military reservations were established. The result is a patchwork of fiscal responsibility for wildland fire protection. About 60 years ago, the fire protection agencies got together and swapped responsibility for fire protection purposes. This was done through an interagency agreement known as the Four Party Agreement, signed by CDF, the USDA Forest Service, and the USDI's Bureau of Land Management and National Park Service. Six counties provide wildland fire protection services under contract with CDF. CDF also works cooperatively with local government, contracting for rural and urban structure fire protection. These agreements allow the fire protection agencies to take a giant step toward an efficient fire protection delivery system.

Key Fire Management Concepts

There are several key concepts in CDF's approach to wildland fire management. CDF fully supports cooperative fire protection. Severe fire conditions frequently challenge all of the fire services in California, sometimes requiring national support. Cooperative efforts such as FIREScope, the California Master Mutual Aid Agreement and a five western state compact are examples of statewide

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, California.

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cooperative efforts. CDF also runs fully integrated initial attack operations on the basis of mutual threat and automatic aid at the local level. The department's suppression organization is built on a foundation of aggressive initial attack. CDF uses a balance of initial attack forces, engines, bulldozers, hand crews, and aircraft to put fires out quickly. Historic analysis of our workload shows episodic fire events with multiple large costly fires. To meet this challenge, CDF operates a statewide command and control system and maintains a depth of resources and participates in mutual aid agreements to staff and manage multiple fire situations. CDF suppresses thousands of fires each year. To meet this workload, the department has built a decentralized organization structure and delegates authority to the fire manager on the fire line. The Department does not rely on suppression alone. We have a fully integrated fire management program that includes fuels management and prescribed fire and all aspects of a modern fire prevention program.

The Fire Workload

The department responds to over 250,000 incidents each year. Of these, about 6,600 are wildland fires that burn about 135,000 acres. About 95 percent of these fires are contained at less than 10 acres. The department has a prescribed fire program for landowners and burns about 40,000 acres per year in fuels reduction, range improvement, and wildlife habitat improvement burns.

Organization and Budget

CDF manages the organization from a Sacramento headquarters, two region offices, 21 ranger units and 6 contract counties, 227 State and 410 local government fire stations, 13 air attack bases, 9 helitack bases, and 41 conservation camps housing 195 fire crews. This organization employs 3,800 full time professionals, 1,400 seasonal firefighters, 5,600 local government volunteer firefighters, 2,600 volunteers in prevention, and 4,300 inmates, wards, and corps members. This staff operates 1,036 fire engines (336 State and 700 local government), 195 crew vehicles, 105 rescue squads, 13 aerial trucks, 58 bulldozer units, 5 mobile communication centers, 11 mobile kitchens, 19 air tankers, 11 helicopters, and 13 air attack planes. CDF's \$452 million annual budget is spent on resource management (\$27 million), the office of the State Fire Marshal (\$10 million), administration (\$38 million), local government fire protection (\$129 million in reimbursements), and wildland fire protection (\$248 million).

California Fire Plan

The department has been shifting its strategic approach to wildland fire protection as it implements the Board's California Fire Plan. The board recognizes the natural role of fire in California's ecosystems, and they recognize that the initial attack organization has achieved a 95 percent success rate.

In their 1996 fire plan, the board set a goal of minimizing costs and losses of wildland fires. In this plan, the Board defined a pro-active framework for wildland fire planning based on several key concepts. First, the Board calls for public stakeholder participation in the planning process. The process is based on a risk assessment of the level of wildland fire protection service, flammability of fuels, frequency of severe fire weather, and public and private assets at risk. The plan identifies high priority areas for pro-active prescriptions to reduce the threat of costly damaging fires. Community-based fuels, ignition management, and suppression enhancement projects are planned and implemented. This risk assessment-based decision process includes tactical and strategic economic models that allow fire managers to test alternative solutions.

This strategic approach has lead to the development of statewide and local Fire Safe Councils. These councils provide a forum for local stakeholders to get together,

assess their fire problem, and define appropriate solutions. Currently, there are more than 50 local fire safe councils of one form or another. The director of CDF has taken one other step with our Federal partners. Two years ago, the director called a summit of the Federal, State, and local wildland fire agencies and interested stakeholders. California's fire problem was discussed during a 3-day meeting. The outcome was the formation of an Alliance for a Fire Safe California. The Alliance partners are working together to remove barriers that prevent local project managers from completing pro-active fire management projects.

The National Park Service Wildland Fire Management Program¹

Stephen J. Botti²

Abstract

The USDI National Park Service (NPS) manages a wide variety of land areas throughout the nation. These lands contain many priceless resources such as historic properties, rare species, critical habitats, and special concern biological communities. They also provide a large infrastructure for visitor services. The NPS has long recognized that wildland fire can be a threat to some of these resources and a benefit to others. For this reason, NPS fire management has emphasized a balance between aggressive suppression and fire use. The NPS utilizes the FIREPRO programmatic analysis to determine appropriate staffing, program support, and funding for each park area. Because the NPS manages so many non-market and non-use resources, FIREPRO does not utilize a cost-plus-net-value-change philosophy to identify a least cost program. Instead, it attempts to define a program that effectively accomplishes resource management objectives while protecting life, property, and other resources for which parks were established. Future enhancements to FIREPRO will focus on using geographic information systems to evaluate the cost-effectiveness of alternative fire management strategies spatially across landscapes and through time. This will require a more precise definition of resource management goals and objectives and improved methods for monitoring ecosystem changes.

The USDI National Park Service (NPS) contains 377 units in 48 states, the District of Columbia, and many overseas territories (*fig. 1*). Within these units, the NPS manages 34 million hectares of land, including 21 million hectares in the state of Alaska. This is the most varied land base of any land management agency in the United States, ranging from the White House, to Gettysburg National Military Park, to famous natural areas such as Yellowstone and the Grand Canyon, to urban recreational areas such as the Santa Monica Mountains.

Some rather unique wildland fire management problems are associated with this geographic variety. Many of the nation's scenic, historic, and ecological treasures are found within National Parks. NPS lands contain more than 29,000 historic buildings, 47,000 known archeological sites, and 30,000 non-historic buildings valued at more than \$6.5 billion. In addition, NPS lands encompass 6

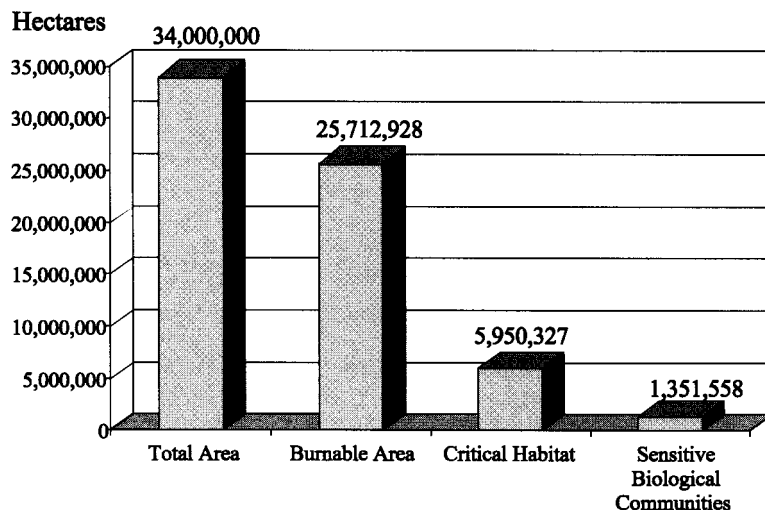
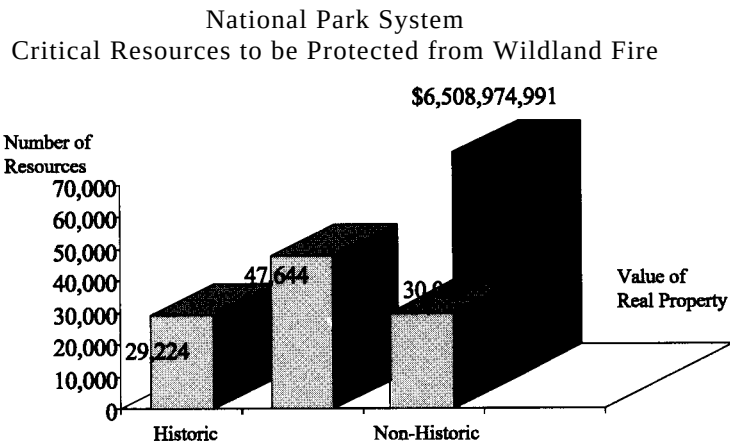


Figure 1
National Park Service, land management profile, 377 units.

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Policy, and Planning: Bottom Lines, April 5-9, 1999, San Diego, California.

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Figure 2
National Park Service, critical
resources to be protected from
wildland fire.



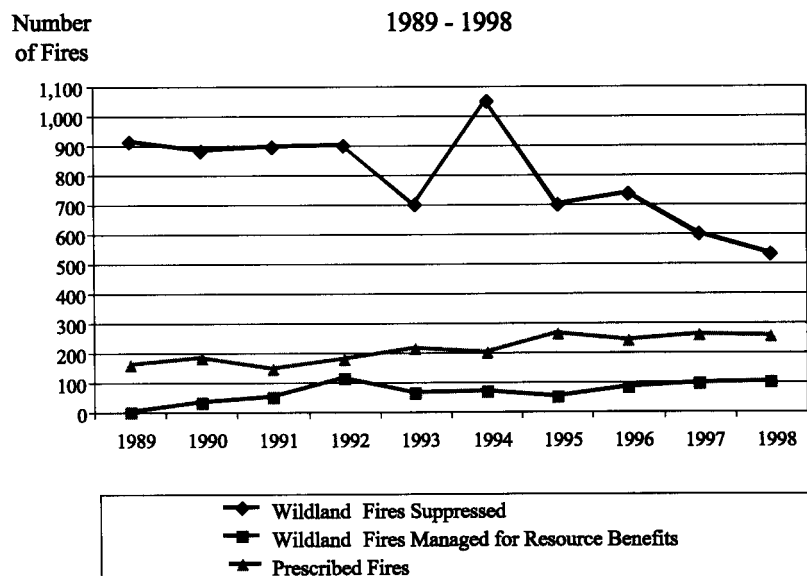
million hectares of critical habitat for a wide variety of endangered, threatened, rare, and sensitive species, and more than 1 million hectares of special concern biological communities (figs. 1, 2). Special concern biological communities include the hardwood hammocks in the Everglades, ohia forests in Hawaii, and giant sequoia groves in Sequoia National Park. These are areas containing rare associations of plants and animals that may be sensitive to a variety of environmental impacts. Protection of these areas may be identified in legislation and policy as one of the primary purposes of a park.

Because critical habitat and special concern biological communities are considered priceless, the NPS cannot allow them to be destroyed by wildland fire. Conversely, many of the NPS sensitive species and biological communities are dependent upon recurring fire for their perpetuation. Because of the dual nature of this relationship to wildland fire, the NPS has emphasized both aggressive suppression of unwanted wildland fires and restoration of natural fire regimes through wildland fire use and prescribed fire. Recent changes in Federal wildland fire policy have solidified this perspective and required no major strategic changes in NPS fire management plans.

Distribution of Wildland and Prescribed Fires in the NPS

In the past 10 years, the NPS has suppressed an average of 791 fires per year, managed an average of 73 wildland fires per year for resource benefits, and set

Figure 3
National Park Service, wildland/
prescribed fire occurrence,
1989-1998.



an average of 210 prescribed fires each year (*fig. 3*). Since the Yellowstone fires of 1988, fire occurrence records show a slow but steady increase in numbers of prescribed fires and wildland fires managed for resource benefits and a slight downward trend in numbers of wildland fires suppressed. During the same time period, the area burned by suppressed wildland fires also has shown a downward trend, while the prescribed burned area has remained about the same, and the area burned in wildland fires managed for resource benefits has slowly increased (*fig. 4*).

During 4 of the past 7 years, the area prescribed burned actually exceeded the area of suppressed wildland fires. Even in 1994, one of the most severe wildfire years on record, the total fire area managed for resource benefits (prescribed and wildland) was about equal to the area of suppressed fires. This demonstrates the increasing emphasis by the NPS on using fire as a resource management tool to restore and maintain natural ecosystems.

NPS Fire Management Economics

The distribution of wildland and prescribed fires throughout NPS units is quite different from the pattern on most other Federal lands and has great impact on the organizational and economic structure of the fire management program. In the past 10 years, 75 percent of the area burned by suppressed wildland fires occurred in only 11 NPS units (3 percent):

<i>Park</i>	<i>Area Burned (ha)</i>
Everglades National Park, Florida	64,670
Denali National Park and Preserve, Alaska	58,840
Yosemite National Park, California	29,070
Yukon-Charlie Rivers National Preserve, Alaska	28,070
Gates of the Arctic National Park and Preserve, Alaska	25,290
Big Cypress National Preserve, Florida	14,850
Saguaro National Park, Arizona	7,290
Yellowstone National Park, Wyoming	7,040
Carlsbad Caverns National Park, New Mexico	5,450
Glacier National Park, Montana	5,160
Santa Monica Mountains National Recreation Area, California	4,480

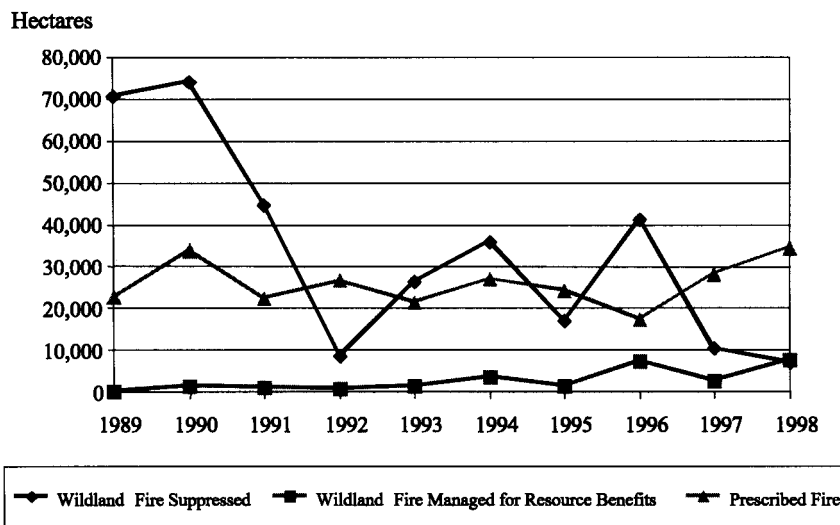


Figure 4

National Park Service, wildland/prescribed fire area burned, 1989-1998.

The situation with fire use is even more dramatic. In the past 10 years, 87 percent of the area burned in wildland fires managed for resource benefits occurred in only seven park units:

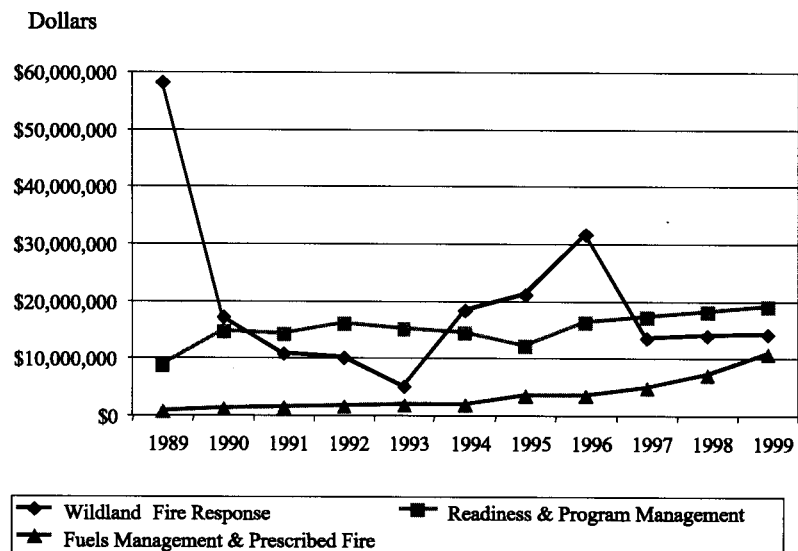
<i>Park</i>	<i>Area Burned (ha)</i>
Sequoia and Kings Canyon National Parks, California	6,350
Glacier National Park, Montana	5,240
Everglades National Park, Florida	4,380
Grand Canyon National Park, Arizona	3,450
Yosemite National Park, California	3,080
Dinosaur National Monument, Colorado	1,740
Yellowstone National Park, Wyoming	1,520

Eighty percent of the area prescribed burned in the past 10 years also was in 7 parks:

<i>Park</i>	<i>Area Burned (ha)</i>
Big Cypress National Preserve, Florida	158,310
Everglades National Park, Florida	17,940
Sequoia and Kings Canyon National Parks, California	7,800
Grand Canyon National Park, Arizona	7,170
Yosemite National Park, California	5,700
Wind Cave National Park, South Dakota	4,880
Badlands National Park, South Dakota	4,470

The goals and objectives for protecting people, property, and historic resources, and enhancing natural resources in these few parks have a tremendous impact on fire management economics in the NPS. Fire management expenditures can be grouped into three program areas: readiness and program management, wildland fire response, and fuels management and prescribed fire (fig. 5). Readiness and program management involves planned and programmed expenditures for program leadership and for staffing and equipment required for responding to normal year unplanned ignitions. Wildland fire response expenditures occur on individual incidents and cannot be planned in advance. These involve the full range of appropriate management responses on unplanned ignitions, from aggressive suppression to monitoring, and also include

Figure 5
National Park Service, wildland fire management expenditures (adjusted to 1999 dollars), 1989-1999.



emergency rehabilitation actions. Fuels management and prescribed fire expenditures are for planned projects, but actual obligations tend to be unpredictable because they are dependent on prescription criteria, smoke impacts, and other constraints. Readiness and program management budgets, which are fixed by Congress, have slowly increased during the past 10 years. During the same period, wildland fire response expenditures have fluctuated depending on the severity of the fire season and the threats presented by wildland fires. Fuels management and prescribed fire expenditures have shown a slow increase, accelerating in recent years because of the increasing emphasis on reducing hazardous fuels and restoring the natural ecosystem role of fire. Expenditures for wildland fire response and for fuels and prescribed fire management are theoretically unlimited; however, amounts in excess of annual budgets require national emergency declarations, supplemental appropriations, or emergency transfers from other budgeted programs.

The costs of wildland fire response and prescribed fire are dramatically different. It is useful to discuss these differences in terms of the relative cost per hectare of each type of operation (*fig. 6*). There are few incentives to control costs on wildland fire incidents, because of the perceived emergency nature of the response and the threats to life, resources, and property. For this reason, those costs have averaged \$813 per hectare over the past 10 years, eight times the average cost of prescribed fires. In 1998, appropriate management response on wildland fires cost 10 times as much per hectare as hazardous fuels reduction and prescribed burning to restore the natural ecosystem role of fire. Wildland fire costs per hectare have fluctuated depending on the size of fires, the threats they present, and resources available at the time. Prescribed fire costs per hectare have shown a slow and steady increase as larger and more risky areas are burned and more resources are invested in the program. Managers control the costs of prescribed fires by establishing ranges of acceptable costs for projects with similar characteristics. For example, the costs of projects within a certain size range, in a particular fuel type, are evaluated against similar historic projects to determine if they are acceptable. Projects that exceed a statistical range of costs are not approved or require special justification.

NPS Fire Program Analysis - FIREPRO

Similar to other Department of the Interior bureaus and the USDA Forest Service, the NPS must demonstrate that its fire expenditures are both effective and efficient. Accountability requires the NPS to defend the relationships between investments in readiness, program management, prescribed fire, and appropriate management response on wildland fires. The NPS uses a system-wide analysis of

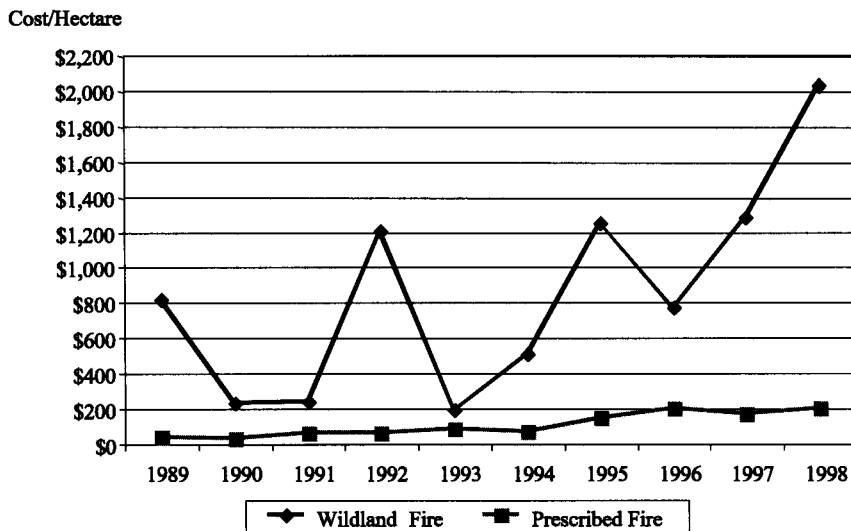


Figure 6
National Park Service, cost per hectare (adjusted to 1999 dollars), wildland fire/prescribed fire, 1989-1998.

program workload and complexity called FIREPRO to determine appropriate staffing and funding targets. This analysis identifies the staffing and program support required to achieve a 95 percent success rate on initial wildfire suppression response and provides adequate program planning and oversight. FIREPRO analyzes fire occurrence and weather records for a normal year and historic initial response success to determine the proper mix of fire engines and crews. Monitoring and management requirements for wildland fires managed for resource benefits are calculated from historic records of the numbers and duration of such fires. In addition to the cost-acceptability assessment, prescribed fire projects are prioritized through a national ranking system on the basis of values to be protected. To determine if prescribed fires are achieving long-term resource management objectives, FIREPRO determines the staffing required to implement a fire effects monitoring system. This system monitors changes in fuels and vegetation indefinitely into the future.

Project rankings, cost profiles, and initial response success alone are insufficient to measure whether expenditures are efficient and effective. Any discussion of fire economics in the NPS must be guided by a firm understanding of its land management objectives. The purpose of wildland fire management in the NPS is neither to produce a good safety record for firefighters, maintain a modernized fleet of fire engines and aircraft, nor achieve the least cost program. The purpose is to protect lives, property, and resources from damage and to use wildland fire to achieve a wide range of resource management benefits. In particular, a primary purpose is to restore and maintain fire dependent ecosystems and reduce the threats of unwanted wildland fire through reduction of hazardous fuel accumulations. It is the accomplishment of these goals and objectives that should be the focus of economic analyses and program performance assessments.

Agencies that produce market value commodities from their lands have incorporated such values into an analysis of fire program cost plus net value change in resources (C+NVC) to determine the least cost program. The NPS has been faced with a more difficult situation because of its emphasis on protecting non-market and non-use resources. Determining NVC for the potential loss of the General Sherman Tree or the Battleship Rock pictographs left by the ancestral Pueblo Indians enters the realm of individual philosophical and spiritual values. Nevertheless, such resources are not of infinite value, and their protection cannot be based on the total lack of cost controls. Likewise, the benefits of restoring and protecting a mixed conifer ecosystem by reestablishing the natural role of frequent low intensity surface fires is difficult to quantify. Even quantifying the economic benefits of reducing hazardous fuels has proved difficult. Although the relationship between changes in fuels and changes in fire behavior can be predicted, the unpredictability of ignitions and the conditions under which they will occur introduce a large degree of uncertainty into the relationship between fuels management costs and suppression costs. Further complicating this analysis is the fact that almost all prescribed fires in the NPS are designed to produce ecosystem management benefits in addition to reducing hazardous fuels that might threaten lives and property.

For this reason, the NPS believes that the proper way for it to determine appropriate fire management budgets and control wildland fire expenditures is to focus on the effectiveness of various budget levels and response strategies in achieving long-term land management goals and objectives. For instance, in the hypothetical analysis depicted in (*fig. 7*), management strategy "C" is as effective as "A" but costs less, whereas strategy "B" costs the same as "A" but is more effective. Management strategies that lie along the cost-effectiveness analysis (CEA) frontier provide the most cost-effective alternatives for given budget levels. The dashed line depicts a possible future evolution of the cost-effectiveness frontier for a given set of

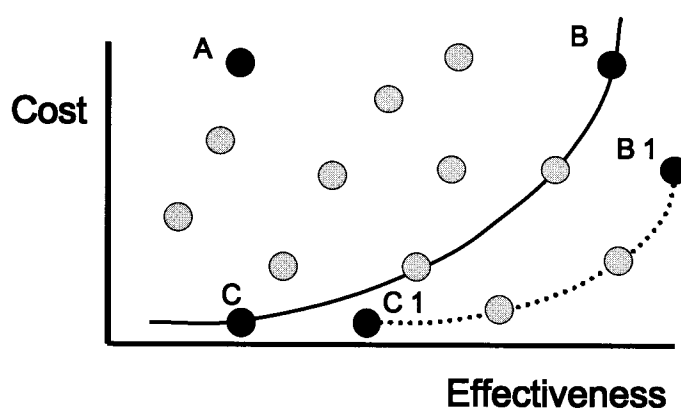


Figure 7

Cost effectiveness analysis (CEA).

strategies (*fig. 7*). Reducing hazardous fuels and restoring natural fire regimes and vegetation structures will, in time, tend to flatten the CEA frontier curve so that strategies such as C and B become more effective and less costly (*fig. 7*). Some fuel types require repeated treatments to achieve fuel reduction and ecosystem restoration targets. Each subsequent fire becomes simpler and less costly, and the overall effectiveness of the strategy in reducing the risks of catastrophic wildfire increases through time. FIREPRO is the first step in developing this process. Future enhancements will focus on quantifying precise resource management goals and objectives and developing methods to measure how well these are achieved. This will involve evaluating vegetation and fuel changes through time at the ecosystem level, which is currently beyond the capability of the fire effects monitoring program in FIREPRO.

Summary

The National Parks discussed earlier will be the primary focus of such efforts because that is where fire management has the greatest impact and where most of the money is spent. Technologies for spatial analysis of fuels, vegetation, fire history, fire regimes, and values across a landscape will soon allow the NPS to model the effectiveness of alternative fire management budgets and strategies. Constraints on the use of fire, such as smoke and visitor use impacts, can be assessed and used to modify resource management goals and objectives. By analyzing changes in fuels and ecosystems in both space and time, managers will be able to identify the most cost-effective program for the long term. Rather than focusing exclusively on immediate trade-offs between the costs of emergency response capability and economic values protected, the NPS strategy is to view investments in prescribed fire and wildland fire use as capital investments that will return benefits in the future. These benefits will include reductions in suppression readiness costs and the exorbitant cost of fighting catastrophic wildfires.

Federal Funding of Wildland Fire Management Programs: What Will One Billion Dollars Buy?¹

Gardner W. Ferry²

Abstract

The wildland fire management program has maintained strong support from the public and Congress. This program costs the public about 1 billion dollars per year; thus, it receives much scrutiny by congressional committees. All of the Federal agencies with wildland fire management programs have a common budget development process. Funding received from Congress for fire management encompasses both the plannable and predictable workload and the unpredictable and unplannable workload associated with suppression and emergency fire rehabilitation. It also includes funds for the use of prescribed fire and mechanical fuel treatments to reduce the occurrence of wildland fires and restore fire to ecosystems.

The Federal budget for wildland fire management programs is about 1 billion dollars per year. Because this program functions in an emergency atmosphere and involves thousands of people, impacts all sectors of society, and involves 1 billion dollars, it has a high risk factor for waste, fraud, and abuse. As a result, the executive and legislative branches of the Federal government--through their committees, offices, and oversight organizations, such as the General Accounting Office (GAO) and the Office of the Inspector General (OIG)--invest a lot of time looking at the plans, budgets, and expenditures of Federal agencies with wildland fire protection responsibilities. Although the primary focus has been on expenditures, the scrutiny by the appropriations committees on the merits of the program, its components, and fire management plans has become intensive.

The wildland fire program has maintained strong support from the public and Congress. The fire budget and personnel ceilings have corresponded to inflation; and although fire management has never received funding to fully implement what the plans identify as the most cost efficient and effective organization, the Federal fire programs have fared better than the agencies' resource management programs. Much of this support is a result of the public's fascination and fear of fire and the political responsiveness to the constituents' concerns regarding the protection of life and property. To a lesser extent, the quality of our plans, workload analysis, and the ability to use this data to make a convincing budget request has resulted in congressional support for the program.

Budget Development Process

All five Federal agencies with wildland fire management programs (the USDI's Bureau of Land Management [BLM], Bureau of Indian Affairs [BIA], Fish and Wildlife Service [FWS], National Park Service [NPS], and the USDA Forest Service [USFS]) have a common budget development process. The fire management plans (FMP's) are the basis of the budget development process. Through the workload analysis used in fire planning, the Federal agencies establish a desired funding level. The desired funding level represents the cost of the most efficient program or organization meeting the fire management objectives. The figure for the desired funding level becomes the basis of negotiations that establishes how much the President will request from Congress for wildland fire management. The process follows these steps:

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, Policy and Policy planning: Bottom Lines, April 5-9, 1999, San Diego, California.

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- The Departments usually have bottom line budget numbers they are working with and by the time the agencies even initiate the formal budget estimate process, something significantly less than the most efficient level (MEL) becomes the agencies' "revised" starting point.
- The Departments then provide their budget estimate to the Office of Management and Budget (OMB). OMB has the role of ensuring that all of the funding needs of the agencies and programs of the government do not exceed the President's target. After a process of "passbacks" and "appeals" between the Departments and OMB, a dollar ceiling for the Federal wildland fire management program is set. Then the executive branch of the government puts together the President's budget justification and sends it to Congress.
- The House and Senate Appropriation Committees review the justification and have formal hearings and informal briefings with the Departments and the agencies. This results in a series of questions and answers (commonly referred to as Q&A's) and eventually the House and the Senate each develop their budget or "mark." If the House and the Senate do not initially agree, they conference, and a Committee resolves the differences. Congress votes on the budget bill, and once passed, it is sent to the President.
- Once the President signs the appropriation bill, it becomes an act and the law. The agencies then proceed with the allocation process and budget execution (implementation of the budget).

All five Federal agencies' wildland fire management funding is received under the title of "Wildland Fire Management Appropriation." The appropriation comes through the Department of the Interior (USDI) as Title I for the USDI agencies and Title II for the USFS. The Wildland Fire Management Appropriation is divided into two activities:

- Wildland Fire Preparedness
- Wildland Fire Operations

The Wildland Fire Preparedness activity focuses on the plannable and predictable workload and is generated by FMP's. The Wildland Fire Operations activity focuses on the relatively unpredictable and unplannable workload. The amount needed for suppression and rehabilitation is generated by the 10-year running average cost of actual suppression and rehabilitation activities, combined with a cost target (generated from FMP's) for fuels management operations.

The suppression subactivity within Wildland Fire Operations provides the costs of managing wildland fires. It is also the source of Severity Funds. Fire Severity Funds are used to improve initial attack response capabilities when abnormal fire conditions occur resulting in fire seasons starting earlier than normal, lasting longer than normal, or exceeding average high fire danger ratings for prolonged periods. Having access to Severity Funds is critical since the analysis that identified the most efficient organization and its costs was based on an average annual workload; not a worse case scenario.

The Hazardous Fuel Reduction Operations subactivity created by Congress in fiscal year '98 provides a more flexible funding authority in support of aggressive use of fire and mechanical fuel treatments with the goal of reducing the occurrence of uncharacteristically severe wildland fires and restoring fire to ecosystems.

Bureau of Land Management Fire Program

The BLM manages about 264 million acres of land, which is about one-eighth the size of the U.S. It also manages another 300 million acres of subsurface mineral resources. Although the Bureau has the full range of wildland fire management activities on its 264 million acres, it also has protection responsibility on an

additional 123 million acres for a total of 388 million acres. The Bureau generates about \$1.5 billion in annual revenues from its multiple uses of the land. The Bureau's workforce includes about 10,000 permanent, temporary, and seasonal employees; this categorizes the Bureau as a medium to small agency.

The operations of the BLM's fire program reflect the dominance of certain fuel types and land ownership patterns. The most common vegetation types are the grasslands, brushlands and woodlands. Although the Bureau has some of the most productive forest lands in the world, which are found in western Oregon, they represent a small percentage of the Bureau's lands. The Bureau also has responsibility for fire management for most of the nation's taiga and tundra. The Bureau's unenviable land ownership pattern is also a strong influencing factor on the choice of fire management strategies and tactics and even policies. Although the Bureau has numerous million acre parcels of land that are only infrequently broken with state and private holdings, there are also millions of acres of scattered ownership consisting of parcels as small as 40 acres to blocks of sections and townships. The rangelands and brushlands can be characterized as dry with infrequent sources of surface water.

As the western U.S. population grows and more people desire to live in rural settings adjoining Federal land knowing they won't be commercially developed, and with the prevalence of fine fuels characterized by extreme rates of spread, the BLM is faced with the ultimate wildland /urban fire interface problem.

Excluding Alaska, the Bureau's suppression workload is predominantly initial response and extended attack with infrequent long duration campaign fires. Whereas 20 years ago the Bureau scoffed and chided itself for retardant use on grass and brush fires, currently the entire concept of values threatened and political oversight has been reversed because of the wildland / urban interface issue and the loss of critical habitat to introduced annual grasses. The Bureau's suppression program focuses on heavy duty, rough terrain wildland fire engines, back fires and burnouts, and retardant aircraft, especially the Single Engine Air Tankers (SEATS). In Alaska the focus is on aviation, water delivery, and hand crews. Roads are limited in Alaska, traversing the land for any distance on foot can be incredibly slow, and water and mosquitos are prevalent. Millions of acres in Alaska fall into the fire planning category of "limited suppression." Limited suppression exists where there are massive areas that do not present risk to life and property, and present no unacceptable environmental issues. The appropriate action for these fires is surveillance and letting fire play its natural role. Where isolated structures are threatened, specific protection is taken just around those structures. If the surveillance analysis indicates a village may be threatened, burnouts connecting lakes and rivers are a common suppression practice.

In other areas of Alaska where life, property, and commercial values are at risk, the fires are fought aggressively from start to finish. Although most of the fires in Alaska are natural-caused, as opposed to human-caused, smoke is appearing as a major determinant in future fire management policies and actions. The magnitude of number of acres that may be on fire at any one time and burning for several weeks does impact air quality. Although it may be natural and good fire management economics, it is not possible to suddenly put the fires out when commercial aviation is impacted and concerns are raised regarding worldwide smoke. When these events occur, social and non-fire economic values predominate and guide the process.

With the advent of a new source of funding specifically targeted to fuels management for both reduction of hazardous fuels and to restore fire to fire dependent ecosystems, the Bureau's accomplishments and plans to accomplish treatments have been dramatically revised. The Bureau's 10-year average of fuels treatments through 1997 (for non-commodity generated fuels such as logging slash) was a meager 60,000 acres per year. In 1998 the Bureau more than doubled its accomplishments by treating 200,000 acres. The plan for 1999 is to treat about 300,000 acres. We anticipate a leveling off in the growth of acres treated by the

Federal Funding of Wildland Fire Management-Ferry

year 2001 or 2002 at about 500,000 per year. We have a documented example where repeated cyclical burns over a 15-year period reduced the need for two wildland engines. These engines were moved to new areas of high risk.

Because of the dominance of rangelands, brushlands, and woodlands, the primary treatment objective has been to restore fire to the ecosystem, as opposed to hazardous fuels reductions. When we divide the total of all of the 1998 expenditures made with the new fuels funding account by the actual treated acres, we find the average cost per acre was \$35. The range of cost per treated acre varied from \$1,000 in the wildland/urban interface of western Oregon to about \$10 for most of the rangelands.

S e s s i o n



**Large Wildfires and Wildfire Costs:
How Much and Why?**

Chairs Enoch Bell and Douglas B. Rideout

Predicting National Fire Suppression Expenditures¹

Krista M. Gebert,² Ervin G. Schuster²

Abstract

A quantitative tool was developed to predict USDA Forest Service fire suppression expenditures by fiscal year on the basis of fire activity data (i.e., number of fires and acres burned) from Incident Management Situation Reports. Regional regression models were developed with adjusted r-squares ranging from 0.696 to 0.969. National predictions result from aggregating regional predictions. Predictions are made monthly during the fire season, starting in June. Subsequent predictions reflect actual, past expenditure information and the level of fire activity likely to occur in the remaining months of the fiscal year. This tool was used by Fire and Aviation Management to predict fire suppression expenditures for fiscal year 1998.

Since fiscal year (FY) 1970, fire suppression has accounted for more than half of all USDA Forest Service (FS) fire-related expenditures (Schuster and others 1997). Generally, appropriated and emergency suppression funds are enough to support fire suppression activities; however, when extraordinary fire seasons occur, funds held in reserve for other purposes (such as Knutson-Vandenberg Funds) must be borrowed to pay the extra costs. Concern has been expressed in recent years that fire suppression expenditures have been increasing, making it even more difficult to appropriate an adequate amount of suppression funds.

As part of the annual appropriation process, the FS provides Congress with an estimate of the amount of money that will be needed to suppress fires for the current fiscal year. Starting in June each year, Fire and Aviation Management (FAM) must provide the office of the Chief of the Forest Service and the Office of Management and Budget (OMB) with monthly, up-to-date predictions of total FY fire suppression expenditures. Because it is unknown what the upcoming fire season will entail, predicting expenditures is a difficult task, subject to error. Simply averaging the expenditures from previous years may be too general for an acceptable prediction. On the other hand, a detailed, accounting-based prediction may be far too complicated and time consuming.

Another approach might be to increase predictions of fire suppression expenditures by some factor, say 20 percent. However, how does one decide upon the appropriate adjustment? Should it be 10 percent, 20 percent, or 30 percent? In a year as extreme as FY 1994, with fire suppression expenditures of \$685 million, one would have needed to add a factor of 218 percent to the 1990-94 average of \$215 million to arrive at an accurate prediction. In an attempt to improve their predictions, FAM requested the development of a tool for predicting fire suppression expenditures. This study developed a quantitative tool for predicting annual, fire suppression expenditures that can be updated every month, starting in June, making use of available fire information and year-to-date expenditure information.

Methods

Before we began developing models, we discussed various modeling options with FAM. In the end, we decided to use linear regression as the basic prediction tool and to devote substantial effort toward packaging the models and making the tool user friendly. The process of constructing such a tool consisted of two

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Policy, and Planning: Bottom Lines, April 5-9, 1999, San Diego, California.

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phases. The first phase was to develop a linear regression model for each Forest Service region using fire activity data to predict monthly, fire suppression expenditures. The second phase consisted of creating a modeling system comprised of a series of linked spreadsheets to help predict future expenditures. These spreadsheets use fire activity data from previous years to help predict the level of fire activity for the rest of the fiscal year. The predictions of fire activity are then used in the regression models to predict fire suppression expenditures for the remaining months of the fiscal year. These monthly predictions are added to current, year-to-date expenditures to obtain a prediction of annual, fire suppression expenditures. National predictions result from aggregating regional predictions. As a second option, a single national model was also developed.

Phase One: Regression Models

Regression models for predicting fire suppression expenditures were developed for each of the nine Forest Service regions and the Washington Office (WO). An overall, national model was also developed that used national, monthly, fire suppression expenditures as the dependent variable and national, fire activity variables as the independent variables. The dependent variable for each of the regional regression models consisted of regional, monthly, fire suppression expenditures. FAM could not provide us with monthly expenditure information at the regional level that went back to FY 1994 so it was necessary to obtain this information from the regions. In August 1997, a joint letter from the directors of Fire and Aviation Management, Financial Management, and Program Development and Budget was sent to all regional foresters asking them to provide FY 1994-96 monthly, fire suppression expenditures for their region. In addition, expenditures for the WO were estimated by using expenditure data from the National Interagency Fire Center located in Boise, Idaho, which generally accounts for about 98 percent of the WO's fire suppression expenditures.

Although all regional, fire expenditure information was derived from the Forest Service's official accounting record, the Statement of Obligation, problems were encountered in obtaining consistent data for all regions. Some regions had the data readily available; while for others, it was a major undertaking to obtain 3 years of monthly expenditure data for fire suppression. In addition, from FY 1994 to 1996, the fund codes for fire suppression changed and the work activity, Economic Efficiency, which existed in FY 1994 and FY 1995, no longer existed in FY 1996. Some regions had detailed enough information to subtract monthly charges to Economic Efficiency for FY 1994 and FY 1995, making these expenditures comparable to those for FY 1996. However, for other regions we had to subtract the charges to Economic Efficiency by distributing the yearly total among the months in the same fashion as other fire suppression expenditures. After monthly expenditures were obtained for all regions, they were converted to 1996 dollars by using the Gross Domestic Product Implicit Price Deflator (BEA 1997).

Initially, the list of independent variables used for the regression models included monthly, fire-fighting resource information, such as the number of crews and number of helicopters, as well as monthly fire activity data. These preliminary models generally included a mix of fire activity and resource variables. For example, the initial model for the Northern Region (Region 1) consisted of two independent variables: the number of Federal helicopters and the total number of fires. We also developed regional models using only fire activity data as independent variables. Given that there is often a time lag of at least 1 month between the time fire activity occurs and the time the charges are entered into the financial system, we also lagged the independent variables 1 month and included these as potential variables in the models as well.

We presented FAM with both model specification options and allowed them to decide the preferred method. They decided to drop the fire-fighting resource variables from the models for two reasons. First, these resources were deemed a function of the number of fires and the number of acres burned. They were seen as indirect reflections of the primary, fire activity variables. Second, the resource information was very time consuming to convert to a useable form, a task that would require additional personnel at the WO.

The independent variables in the final models, therefore, consisted of regional, fire activity data collected from the Incident Management Situation Reports (SIT Reports). These data included the number of acres burned and the number of fires in each region by fire-fighting agency (USDI's Bureau of Indian Affairs [BIA], Bureau of Land Management [BLM], National Park Service [NPS], and Fish and Wildlife Service [FWS]; the USDA Forest Service [FS]; and state fire-fighting agencies), and the regional totals. The only exceptions were the models for the WO and the national model, both of which used national-level data. It was not possible to obtain SIT Report data earlier than 1994.

Because the SIT Report data are cumulative, we had to subtract the cumulative total at the end of the current month from the total at the end of the previous month to obtain monthly totals. In the process of converting the cumulative totals to monthly figures, it became apparent that the fire activity data on the SIT Reports was often inaccurate. Some errors found were simply a result of inaccurate estimates of the number of acres burned, which were revised over time. This problem, however, led to cumulative totals that declined from 1 month to the next rather than increasing, leading to negative monthly totals.

Other errors found were simply errors. For instance, on one day the cumulative total for the number of fires for a particular agency might be 80. On the next day, someone might inadvertently add a zero and enter 800. This erroneous number, 800, might be carried for days or even weeks before someone noticed the error and changed it back to 80, leading to decreasing cumulative totals and negative monthly figures. We made every attempt to track down and correct errors by looking through the SIT Reports surrounding the time the error was found. The ideal situation would have been to use fire activity data from the National Interagency Fire Management Integrated Database (NIFMID), a more reliable source. Monthly, fire activity data is available from this database but, unfortunately, not until the fire season is over. We needed a source of data that was available at the time the predictions were needed. This left us with using the less reliable, but more timely, SIT Report data for our independent variables.

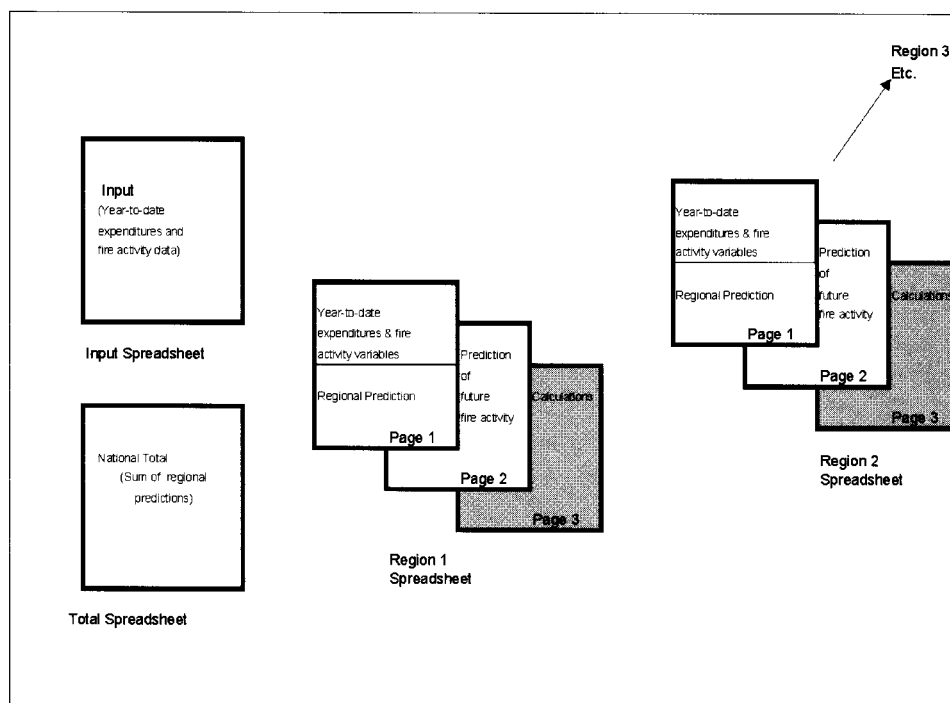
Preliminary regional models were developed by using data for fiscal years 1994-96 for the months June, July, August, and September. These were the only months we could obtain from several of the regions because of their difficulties in obtaining the monthly data and their lack of personnel. In addition, we were missing data on the independent variables from January to May 1994. We did not feel this constituted a large problem for two reasons. First, FAM's initial prediction of fire suppression expenditures is due the beginning of June, with monthly updates needed through September. By the time the first prediction is needed, expenditure information for the months of October through May is already known. Second, the period of June through September includes the bulk of fire activity.

After the decision was made to develop the prediction models, FAM began to collect monthly expenditure data. It was not necessary, therefore, to contact the regions to obtain fire suppression expenditure data for FY 1997. The data for FY 1997 included all regions, including the WO. After we received FY 1997 data, the models were updated, and all dollar values were converted to constant 1997 dollars.

The specific independent variables used in each model were selected by using the forward, stepwise regression procedure in the Statistical Package for Social Sciences (SPSS, Inc. 1997) and the "best subsets" regression subroutine in Minitab (Minitab, Inc. 1998). For the forward, stepwise procedure, a significance

Figure 1

Spreadsheet modeling system for predicting total Forest Service fire suppression expenditures.



level of $\alpha = 0.10$ was used to determine variable entry into the model. From the "best subsets" regression routine, we selected those models having the smallest Mallow's C_p (Draper and Smith 1981). Models from the two methods were compared and tested for adherence to basic statistical assumptions. Final models were selected based on adjusted r -square and lack of violation of statistical assumptions.

Phase Two: Spreadsheets

After a final regression model had been generated for each region, a system of 12 linked spreadsheets was created to help predict future expenditures (*fig. 1*). To best meet the needs of FAM, Microsoft Excel³ was used (Microsoft Corporation 1997). The 12 spreadsheets consist of 10 regional spreadsheets, an input spreadsheet (where the user enters month-end SIT Report data and year-to-date fire suppression expenditures), and a total spreadsheet that aggregates the 10 regional predictions into a national prediction.

Each regional spreadsheet has three pages (*fig. 1*). The first page displays year-to-date information (brought in from the input spreadsheet) on regional fire suppression expenditures and the fire activity variables used in that model. On the bottom of the first page is a separate section for displaying the prediction results. The second page is used to predict future fire activity for each fire activity variable in the regional model. With little knowledge of what the fire season will entail, a reasonable prediction of fire activity would be the expected value or the average. As the fire season progresses, information about the current fire season can be used to refine the predictions. Current fire activity can be compared to the average, and the average can be adjusted as needed. The second page, therefore, compares current cumulative fire activity (from page 1) to the 1994-1997 average (calculated on page 3) and computes the difference (in percentage terms). These percentages can be accepted by the user as being indicative of the rest of the fire season or the values may be altered to reflect any additional insights the user may have about the remainder of the fire season.

The calculations for the regional prediction are conducted on page 3 of each regional spreadsheet. The calculation procedure consists of three steps: the 1994-97 averages of each fire activity variable for the months of June, July, August, and

³Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

September are calculated and then revised by increasing or decreasing the average according to the percentages entered on page 2 of the spreadsheet (the predicted trajectory); the revised values are entered into the regression equation to obtain a predicted value for each month; and the predicted values are linked to the first page and added to the current year-to-date cumulative expenditures. A prediction of the fiscal year fire suppression expenditures for that region is then displayed at the bottom of the first page of the regional spreadsheet. The final step is to aggregate the 10 regional predictions into a national prediction on the "Total" spreadsheet. Included in the total spreadsheet are input cells for entering the fiscal year being predicted and the inflation rate for the previous year. Predictions are in constant dollars and need to be transformed back into current year dollars.

For discussion purposes, the modeling system consisting of the 10 regional regression models and the 12 linked spreadsheets is called the "regional aggregation model." In contrast, the other system, consisting of the single, national-level regression model and a single spreadsheet (containing the same three pages as the regional aggregation model) will be referred to as the "national model."

Results

The initial, 1994-96 regression models, which included fire-fighting resource variables, fit the data well, with an average adjusted r-square for all models of 93.9 percent. When the resource variables were excluded from the analysis, the average adjusted r-square dropped to 91.0 percent. However, the gain in implementation simplicity, as a result of using only the fire activity data, was worth more than the small loss in predictive power. When the FY 1997 data were included in the models, the average adjusted r-square for the regional models decreased to 89.0 percent.

Problems with modeling fire suppression expenditures were encountered in three regions. For the Southern Region and the Eastern and Alaska Regions (Regions 8, 9, and 10, respectively), regional fire activity variables did not adequately explain the variation in expenditures. The models did so poorly that alternative modeling options were sought. The reasons for poor performance varied somewhat by region. For the Southern Region (Region 8) the fire season ends by June. Expenditure data for the last 4 months of the fiscal year seemed to consist mainly of accounting adjustments, rather than expenditures on actual fire activity. In Alaska (Region 10), most expenditures are for fire activity outside of the region because of the small number of fires that actually occur in Alaska. Alternative models were developed for these three regions that used fire activity data from other regions as the independent variables in the models. We do not feel that this caused any serious problems because the alternative models fit the data well with adjusted r-squares ranging from 0.825 to 0.947, most of the fiscal year expenditures for Region 8 were already accounted for in the year-to-date expenditures, and expenditures for the Eastern Region (Region 9) and Alaska (Region 10) are only a small percentage of total fire suppression expenditures (an average of 2.8 percent for 1994-97).

Rather than show all the regional regression equations, for purposes of discussion we will focus on three of the regional regression equations developed for the regional aggregation model and the one regression equation for the national model (*table 1*). The Northern Region (Region 1) model had the highest adjusted r-square of the 10 models (0.969); the WO model had the lowest adjusted r-square (0.696); and the Eastern Region (Region 9) model is one of the three models that used independent variables from another region (in this case, the Northern Region). All regression models are reported in "deviation from the mean" form (Draper and Smith 1981, Pindyck and Rubinfeld 1981). The independent variables are transformed by taking the observed value for a variable and subtracting the mean for that variable. A new regression is estimated

Predicting National Fire Suppression Expenditures-Gebert, Schuster

Table 1-Selected regression models for predicting USDA Forest Service fire suppression expenditures.¹

Independent variables	Regression coefficients			
	Region 1	Region 9	WO	National model
Acres burned - FS (National total)			47 (12)	195 (36)
Acres burned - FS (National total lagged 1 month)			42 (13)	209 (37)
Number of FS fires (Region 1)	11,496 (1,492)			
Acres burned - NPS (Region 1)	1,917 (124)			
Acres Burned - FS (Region 1)		32 (5)		
Acres Burned - BLM (Region 1 lagged 1 month)		1,011 (82)		
Constant	7,960,820 (503,343)	1,927,672 (122,710)	13,459,274 (2,583,666)	80,927,557 (7,574,390)
Adjusted r-square	0.969	0.947	0.696	0.849

¹Dependent variable = monthly, regional, fire suppression expenditures. Standard errors are in parentheses.

by using the transformed independent variables in place of the original variables. The result is a regression equation where the intercept is the mean of the dependent variable (in our case the mean, regional, fire suppression expenditure per month). The coefficients associated with the independent variables are simply adjustments to that mean. For instance, in the Northern Region (Region 1) mean fire suppression expenditures for the months of June through September 1994-97 were \$7,960,820 (in 1997 dollars). Each FS fire above the mean number of FS fires is estimated to add \$11,496 to mean, monthly suppression expenditures, while every additional National Park Service acre burned above the mean number of NPS acres burned adds \$1,917. Regression equations in deviation form are easier for users to understand because confusion accompanying interpretation of intercept terms is avoided, especially if the intercept is negative.

After the models were developed, we inserted the estimated equations into the spreadsheet program and proceeded to test how well they did at predicting fire suppression expenditures for FY 1994-97. Ideally, the tests should have used data other than those used to build the regression models. However, we could not afford to withhold any of the observations for testing purposes because we only had 15 observations in the final data set. Therefore, we tested the accuracy of the predictions by using the same data used to build the models.

All predictions, except those done at the end of May, are the results of accepting the fire activity trajectories proposed by the spreadsheet program. Predictions as of the end of May were done by assuming no change from the 1994-97 average because too little fire activity had occurred by that time to make any meaningful comparisons with the average. The proposed trajectories are calculated on the second page of each regional spreadsheet by comparing current cumulative fire activity to the 1994-1997 average. One line (or series) on the graphs for each independent variable shows, by month, the 1994-97 average, cumulative values for that variable (*fig. 2*). The other series shows the cumulative values for the current year, allowing the user to visually compare the current trajectory of fire activity to the average.

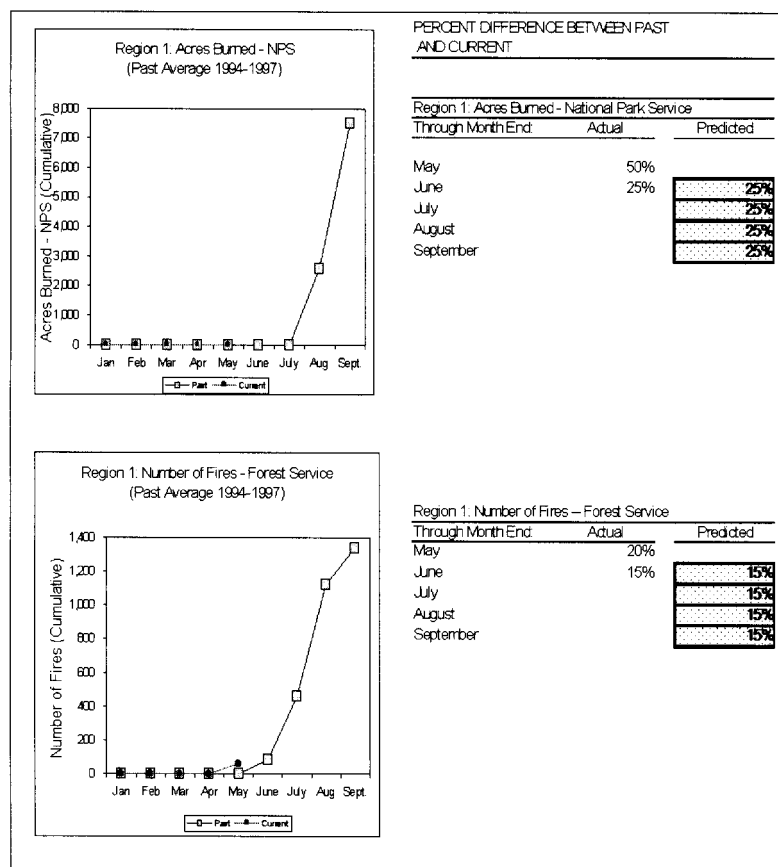


Figure 2
Illustrative fire activity prediction
page from regional spreadsheets.

To the right of each graph, under the heading "Actual," are values showing the difference (in percentage terms) between the 1994-97 average and current, cumulative fire activity as of the end of the previous month (May-August) (*fig. 2*). These are the values we used to test the system. To the right of these values, under the heading "Predicted" (*fig. 2*), are shaded input cells where the user can enter a prediction of what this difference will be (in percentage terms) for the remaining months of the fiscal year (Because the first prediction is not needed until June, the model only predicts the level of fire activity for the months of June, July, August, and September). The predicted values entered by the user may or may not be the same values shown under "Actual," depending on whether it is believed the rest of the fire season will follow the trend shown. For instance, in *figure 2*, under the variable "Region 1: Acres Burned - National Park Service," in the row labeled "June," the value "25%" indicates that, as of the end of June, the number of NPS acres burned was running about 25 percent above the 1994-97 average. The value next to May was the difference at the end of May. The user may decide that the trend shown after "June" will continue for the remaining months of the fiscal year. In this case, "25%" would be entered in the input cells following June, July, August, and September. However, this could be increased or decreased depending on what is anticipated for the rest of the fire season. For example, suppose the belief is that the number of NPS acres burned will not follow the current trajectory, but rather fire activity will increase even more in the coming months (relative to the current trajectory). Then a value of "50%" might be entered in the input cells rather than a value of "25%," indicating that the number of acres burned will run more above the average than the trajectory shows. The same procedure is followed for the remaining fire activity variables in the model.

Table 2—Actual and predicted Forest Service fire suppression expenditures for 1994-1997: regional aggregation model versus national model.

Predicted expenditures (MM\$)			Actual FY expenditures (MM\$) ¹
Regional aggregation model	National model		
1994 Prediction			
As of the end of May	\$372	\$369	
As of the end of June	\$426	\$358	
As of the end of July	\$544	\$505	
As of the end of August	\$601	\$562	
As of the end of September			\$636
1995 Prediction			
As of the end of May	\$406	\$387	
As of the end of June	\$238	\$277	
As of the end of July	\$273	\$275	
As of the end of August	\$206	\$225	
As of the end of September			\$207
1996 Prediction			
As of the end of May	\$458	\$451	
As of the end of June	\$619	\$691	
As of the end of July	\$562	\$606	
As of the end of August	\$555	\$580	
As of the end of September			\$507
1997 Prediction			
As of the end of June	\$268	\$155	
As of the end of July	\$205	\$154	
As of the end of August	\$187	\$168	
As of the end of September			\$162

¹ Actual FY expenditures may not match reported figures because of accounting adjustments.

Prediction results were determined for the regional aggregation model and for the national model for FY 1994-97 (*table 2*). For the most part, predictions steadily improved as the fire season progressed. For the regional aggregation model, by the end of August, predictions were within 10 percent of actual fire suppression expenditures for all years except FY 1997. In fact, for FY 1994 and FY 1995, predicted fire suppression expenditures were within 5 percent of actual expenditures. For FY 1997, the final prediction at the end of August overstated fire suppression expenditures by almost 15 percent, probably because the 1997 fire season was relatively light compared to the other years used to build the models.

The national model did worse than the regional aggregation model at predicting all years except FY 1997. The reason for the poorer performance of the national model could be twofold. First, the national model did not fit the data as well as the regional models. The adjusted r-square for the national model was 84.9 percent, as compared to an average of 89 percent for the regional models. Second, predicting the level of fire activity may be more difficult for the nation as a whole, as compared to each region. Individual regions are likely to be more homogeneous with regard to fire activity than is the entire country. Heavy fire activity in one particular region could sway the figures for the whole nation, when, in reality, most of the country may be experiencing a relatively mild fire season.

After reviewing the results, FAM decided to use the regional, aggregation model to aid them in predicting fire suppression expenditures for FY 1998. Staff members tried several different techniques for predicting the level of fire activity for the 1998 fire season. Print-outs of the current trajectory as compared to the average (from page 2 of each regional spreadsheet) were given to four members of the FAM staff. They were asked to provide input as to whether the remainder of the fire season would follow the current trajectory, and if not, what they predicted the rest of the fire season would entail. Another technique used fire severity maps for predicting future fire activity. Lastly, the model was run by using the trajectories proposed by the spreadsheet program. When the data become available, the results of each technique will be compared to the actual

fire suppression expenditures for FY 1998 to determine which technique most accurately predicted fire suppression expenditures.

Discussion

The main advantage of the prediction tool we developed is that its predictions can be easily updated. Rather than making a once-and-for-all annual prediction, predictions can be revised and refined as the fire season progresses. Up-to-date information on year-to-date expenditures, as well as revised predictions of fire activity, can be used to refine the predictions. This is important because of the difficulty of anticipating the magnitude of the upcoming fire season when the first expenditure predictions are needed.

Ease of use was an important consideration in developing the tool. FAM was directly involved in design decisions in order to better ensure the product would meet their needs. Initially, the spreadsheets were automated by macros to take the user step-by-step through the entire process so that users unfamiliar with the operation of spreadsheets could easily use the tool. In the end, however, FAM decided they preferred a non-automated version that would give them greater control over how the data was entered. After using the tool for the 1998 fire season, FAM stated they were pleased with the basic design of the tool. They did make some suggestions for improvements that we will incorporate in the updated models for FY 1999. For example, they requested that the system of 12 spreadsheets be incorporated into one, large, multi-page spreadsheet.

As mentioned before, fire activity data were very good predictors of fire suppression expenditures. With the exception of the WO model, at least 75 percent of the variation in monthly, fire expenditures could be explained by one or two fire-activity variables in the regional models. In fact, four of the regional models explained more than 95 percent of the variation in fire suppression expenditures. The excellent performance of these models came as a bit of a surprise, especially in light of an inconsistency we discovered in collecting data. The inconsistency was that fire suppression expenditure data were available only "by" region; that is, regional expenditures consisted of all money that was spent by the FS regional organization on fire suppression activities, regardless of where the fire activity occurred. For instance, expenditures by the Northern Region (Region 1) organization might include money spent on fighting fires in the geographical borders of Region 1 or any of the other eight regions. However, all fire activity data pertained to the geographical region where the fires occurred. It was not possible to obtain information on fire expenditures that occurred only "in" the geographical region, nor was it possible to obtain fire activity data to match the expenditures "by" a region. Therefore, we were left with making a rather large assumption that fire activity *in* a geographical region is a good indicator of the amount spent on fire suppression *by* a regional organization. Given how well the models fit the data even with this problem, we believe that if the "by" region versus "in" region dilemma could be resolved, the accuracy of the predictions would improve.

Problems with the accuracy of the predictions can be attributed mainly to the inability to accurately predict future fire activity. It does not seem necessary to spend a lot of time improving the models themselves given how well they fit the data. However, even good models will perform badly if estimates of the independent variables are bad. The next step in the process, therefore, is to derive a process for predicting fire activity. Several techniques were tried by the FAM for the 1998 fire season. Results of the different techniques tried by FAM for FY 1998 will be analyzed and methods to improve predictions will be sought.

It is important to remember, however, that even the best regression models are subject to statistical error and will not provide perfect estimates. When we tested our models using the actual, correct values for the fire activity variables, rather than predicted values, the difference between actual fire suppression

expenditures and predicted fire expenditures ranged from 5.89 percent for FY 1996 to 8.68 percent for FY 1994. Nevertheless, if inaccurate estimates of the independent variables are used in the models, the error will be even greater.

Though we have not yet received the actual results of the techniques they tried, FAM staff members have stated they were pleased with how the tool performed during the FY 1998 fire season. Predictions ranged from about \$275 million to \$320 million. Actual FS fire suppression expenditures for FY 1998 were \$218 million. The large difference between the predicted and actual expenditures was felt to be a result of the inordinate amount of fire activity on state lands in FY 1998. Though the FS provided assistance on these fires, it was reimbursed for the majority of the expenses associated with these fires. Before reimbursement, FS fire suppression expenditures were about \$300 million, an amount much closer to that predicted. The predictions made using input on future fire activity from four members of the FAM staff were responsible for the wide variations in the predictions. The predictions obtained by using the fire activity trajectories proposed on the spreadsheets and by using the fire severity maps fell in about the middle of the range: Because even the highest prediction was less than the amount of fire suppression funds already available, the FS did not ask Congress for any additional funding; consequently, it was not necessary for FAM to choose one of the predicted amounts as the "correct" amount. Next year, in order to arrive at a single prediction, they may average the predictions from several of the techniques.

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Issues in Large Wildfire Suppression Cost Reduction: An Operational Perspective¹

Richard J. Mangan²

Abstract

To significantly reduce the costs of fighting large wildfires, fire managers must address the most costly areas. These areas are in aviation resources; equipment, food, showers, and toilets (56.6 percent of total costs); and in personnel (31.7 percent of total costs). Because many of these costs are under the control of the Incident Command System's operations section chief, careful review could provide some opportunities for reductions. Such opportunities include pulling back resources when extreme fire behavior conditions are forecast, using natural barriers rather than constructed fireline when conditions permit, and letting the fire burn out rather than putting it out during mop-up when conditions permit.

Introduction

Wildfires are big business. Every year in the United States fires burn millions of acres. Numerous contractors, hundreds of aircraft, and tens of thousands of firefighters suppress the fires at a cost of hundreds of millions of dollars.

From June 1 to July 22, 1998, Florida experienced 2,282 wildfires that burned 499,477 acres, mostly on State-protected land. More than 10,000 firefighters from 47 states constructed more than 1,000 miles of fireline to suppress these fires. One hundred and fifty-six aircraft supported them. Suppression costs were estimated at \$160 million.

Across the United States in 1998, 81,043 wildfires burned 2,329,704 acres. This figure is based on the agencies that report their fires to the National Interagency Fire Center (NIFC) in Boise, Idaho. Suppressing these wildfires may have cost more than \$1 billion.

Large fires are not a new phenomenon in the United States. In 1910 vast areas of the country were burned over. A decade-by-decade comparison since then shows little variance in either the numbers of fires or the number of acres burned across the country.

A number of factors have been changing fire suppression methods (especially on the largest wildfires):

- The reduced Federal workforce in natural resources agencies.
- Changing forest health conditions that are often a result of previous fire exclusion practices.
- Changes in the fire camp environment to meet the needs and expectations of the 1990's workforce.
- The public's and media's expectations.
- The politics of wildfire at the local, State, and National levels. An excellent example of the involvement of politics in wildfire can be seen in the Long Island, New York, wildfire during 1995. Although it only burned 5,000 acres, it drew the attention of New York's governor and senior U.S. Senator, the director of the Federal Emergency Management Agency, the Deputy Under Secretary of Agriculture, and the personal adviser to the President.
- Large-scale climatic events such as El Nino and global warming.
- Escaped prescribed fires and prescribed natural fires in wilderness and parks.
- The public's intolerance of long-term smoke events.

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These factors often work in combination, requiring fire managers to take actions (and spend money) that may not have been needed in earlier years.

Previous Studies

The issue of fire-related expenditures, and specifically the costs of large fires, has come under increased scrutiny during the 1990's. This scrutiny may be a result of the lengthy (and costly) fires in the greater Yellowstone area during 1988. Large fires and lengthy fire seasons during the 1990's have seen the introduction of the "comptroller" position on the Incident Management Team (IMT) to advise responsible line officers on cost issues specific to a single fire. Oversight reviews and studies look at individual fires, season-long expenditures, and long-term trends in suppression costs. These studies offer important insights into large fire expenditures. Many of these fires are managed by National Incident Management Teams that spend more than \$1 million per day. USDA Forest Service fire expenditures from 1970 to 1995 were nearly \$7.9 billion. Costs increased 15.5 percent a year from 1991 to 1995.

Schuster and others (1997) looked at 171 medium and large fires. Twenty very large, expensive fires in 1994 received close scrutiny. The report showed that a significant proportion of large fire expenses were for services such as: aviation resources, equipment, food, showers, and toilets (56.6 percent of total costs); and for personnel, with most of these costs for overtime for regular employees and for hiring casual employees (31.7 percent of total costs). All other expenses for these high-cost fires represented less than 12 percent of the total costs.

Schuster and others (1997) also surveyed incident commanders to determine factors they believed resulted in significant cost increases on large 1994 wildfires. Of the 34 topic areas surveyed, the incident commanders rated only two ("weather during fire" and "access") as being very important. The incident commanders said other factors that increased costs included terrain, fuel loadings, protecting lives and structures, and fire fighter availability, quantity, and quality.

Operational Aspects of Large Wildfire Suppression

Since the mid-1980's, large wildfires in the United States have been managed under the Incident Command System (ICS), an organization structure similar to the military organization for combat. The basic structure includes command, plans, operations, logistics, finance, safety, and information. The operations section is responsible for on-the-ground implementation of strategic decisions made by the incident commander. The other sections support by providing necessary information, equipment, supplies, transportation, and personnel for suppression.

The basic components of the operations section on a large wildfire include:

- Personnel (crews, supervisors, aircraft managers, and others).
- Equipment (engines, dozers, water tenders, lowboys, etc.).
- Aircraft (air tankers, helicopters, lead planes, and air attack).

These elements of the operations section are some of the highest cost items of large wildfire expenditures in recent years.

Personnel

Personnel costs are an important part of the total fire suppression costs. Base pay, hazardous duty pay, and premium overtime are all factors in personnel costs. These factors take on greater significance on large wildfires, given the reduction of personnel available locally to most natural resource agencies. It is not uncommon to transport crews and overhead personnel across the country on large fires. These personnel may need 2 days travel when mobilizing and when

demobilizing. Large personnel costs are incurred in this mobilization process, with no effective suppression action on the fire.

Equipment

Equipment such as engines, dozers, and water tenders are also high-cost items. When equipment supplied by contractors is mobilized to a distant wildfire and placed in operational status 24 hours a day, costs can easily exceed \$1,000 per day for each piece of equipment. Other costs may include the salaries of an operator or crew that are sometimes hired under casual labor authority independent of equipment cost.

Aircraft

Aircraft are the most visible symbol of our fire suppression efforts and our single highest cost resource on a large wildfire. Agencies pay for availability guarantees and per-hour flight costs when employing aircraft. Aircraft costs may account for more than one-third of the total suppression costs on large wildfires.

Both equipment and aircraft require personnel to manage and supervise them. Those personnel and the crews assigned to the fire need three meals per day, often in a remote setting a long way from food service facilities. Daily meal costs under the 1998 fire food service contracts average \$35 to \$40 per day per firefighter.

The Future

To successfully address options to reduce costs on future fires, we must forecast conditions that will affect our expenditures.

Recent trends on large wildfires can give us a fairly accurate picture of future conditions:

- Continued reductions in natural resource agency staffing will increase the use of contractors in the areas of crews, equipment, and possibly Incident Management Teams. Because of the seasonality and uncertainty of the contract work, these resources will generally be higher priced than regular agency personnel and equipment.
- The availability and efficiency of large Type-1 helicopters will increase their use on large wildfires. With their flight rate exceeding \$100 per minute, these helicopters are very expensive.
- Modernization of the air tanker fleet by private contractors will increase costs in this program.
- As more people move into the urban-wildland interface, and as news is broadcast more and more quickly, awareness and interest in wildfires will increase for the general public, media, and politicians.
- The impact of the Federal fire policy review will affect States, counties and wildfire departments involved in large interagency wildfires.

Cost Reduction Opportunities in the Operations Section

Recent attempts to address cost savings opportunities on large wildfires have produced a long list of simplistic suggestions for saving money. These "easy answers" save a small percentage of the total fire suppression bill, but avoid the bigger cost centers and fail to produce significant savings. Such recommendations include:

- Fewer newspapers in the incident base camp.
- No bottled water-use canteens with water from large potable water trucks.

- National Guard trucks instead of school buses for crew transportation.
- No national Type-1 incident management teams; they spend too much money.
- No trainees, human resources specialists, or union representatives on large fires.

The operations section offers many opportunities for cost reductions through application of strategies and tactics. Some cost reduction opportunities include:

- The implementation of fire suppression efforts should be analyzed thoroughly during periods when extreme fire behavior conditions are forecast. If crews, equipment, and aircraft cannot take safe, effective actions during these periods, take them off-line and off-shift.
- A 20-person crew at GS-4 levels for 14 hours costs an additional \$1,900 more than for an 8-hour shift. If they are likely to be forced to retreat to a safety zone during periods when extreme fire behavior conditions are forecast, it would be better to return them to the incident base camp for additional rest, safety, and cost savings.
- It is inefficient and dangerous to fly tankers and water-dropping helicopters under extreme fire conditions. They should be left on the ground.
- Dozers, engines, and water tenders may not be functioning very effectively under conditions when extreme fire behavior is forecast and should be placed off shift.

Constructing and holding fireline is a major function of the operations section. Opportunities to reduce line costs include:

- Using natural barriers instead of constructed fireline.
- Choosing the proper fireline construction method: hand line, dozer line, or fireline explosives (FLE).
- Considering the required mop-up standards in light of the current and forecasted weather and fire behavior conditions. "Let it burnout" is often a more cost-effective alternative than "put it out."
- Considering spike camps closer to the fire work area when travel time will result in long shift times. Transporting crews is a large cost factor when travel times approach 2 to 3 hours per operational period.

Contracting equipment is another significant cost center in the operations section for a large wildfire. The need for 24-hour double shifting and round-the-clock availability of prime movers and lowboys must be carefully evaluated against production efficiency and cost per hour. Accountability for actual hours worked should be emphasized, with single resource unit leaders assigned to monitor time performance as appropriate.

Managing shift times in lanes can be an effective tool for reducing personnel costs. When a 12-hour operational period extends to 15 hours, costs increase by 24 percent. Using the 20-person GS-4 crew discussed earlier, this is an additional \$940 per crew for each operational period.

Managing aircraft flight time, both fixed and rotary wing, offers opportunities for large cost savings in the operations section:

- Using air tankers earlier in the burning period to dramatically increase their efficiency and reduce costs.
- Reducing air tanker flights ordered for public and media visibility rather than for fire suppression effectiveness.
- Ordering the right resource for the job. Large air tankers, single engine tankers (SEATS), and Type 1 and Type 2 helicopters all have unique

characteristics that maximize their effectiveness and efficiency under specific conditions.

- Using Type 1 and Type 2 helicopters as needed rather than merely to retain them. During periods when many Incident Management Teams are competing for such resources, keeping large helicopters depends largely on the daily flight time they have logged. This may result in inefficient use of helicopters, at costs that may exceed \$7,000 per hour. Incident commanders, operations section chiefs, and air operations directors must work closely with the regional and national fire coordinators to ensure that actual and projected needs determine helicopter resource assignments, not just flight hours.

Deciding to declare a fire "controlled" results in a major cost reduction because personnel no longer receive hazard pay. For the 20-person GS-4 crew working 14-hour operational periods, this is a savings of more than \$600. If 30 crews are assigned to an operational period, the savings is nearly \$19,000 per operational period. Deciding to demobilize resources, both personnel and equipment, can result in large savings in salaries and in support costs such as contracted food services.

Conclusions

Wildfires are damaging and costly under the best of conditions, but opportunities exist for significant cost savings with increased efficiency of the operations section of the ICS. To realize the savings, the agency administrator and incident commander must clearly state the objectives of cost reduction and strongly support the necessary actions.

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Analysis of Forest Service Wildland Fire Management Expenditures: An Update¹

Ervin G. Schuster²

Abstract

Soaring expenditures for fire management in the USDA Forest Service have caused substantial concern over fire management costs, especially in light of questions about the role of fire in ecosystems. This report contains analysis of most Forest Service fire management expenditures between fiscal years 1970-98. Expenditure information was obtained from a variety of sources, including electronic files from the National Finance Center, hardcopy information from archived records, and data developed by regional fire and accounting personnel. Results identified statistically significant trends in increased total fire management expenditures, in both nominal and real dollars, with or without the fiscal year 1994, the record expenditure year. When expressed in constant 1998 dollars, fire preparedness expenditures showed a statistically significant compound growth rate of 3.4 percent annually, while no trend could be discerned for fire operations expenditures. Similarly, no statistical trend in annual fuel treatment expenditures could be detected over the fiscal years 1970-98 period, although a statistically significant compound growth rate of 20.1 percent annually was found for the 1990's.

Fire prevention and control have always been important to the mystique of forestry and the USDA Forest Service. Everyone knows of Smokey Bear and envisions smokejumpers parachuting to fires. But more recently, questions have been raised about the role of fire in ecosystems and the enormous costs of fire control. Seemingly, the costs of control are out of control. Expenditures in fiscal year (FY) 1994 caused considerable concern.

In FY 1994, the expenditures for Forest Service fire management reached a record-breaking total of nearly \$1 billion. Because of these soaring expenditures for fire management, and the recommendations of the *Strategic Assessment of Fire Management* report (USDA Forest Service 1995) to address them, the Fire Economics Assessment Team was chartered by Forest Service, Fire and Aviation Management (FAM) staff in 1995. The Team was charged to review current fire management expenditures and their trends and identify opportunities to reduce them. The Team's report was submitted during September 1995 (Bell and others 1995) and later published in an abbreviated format (Schuster and others 1997).

This paper summarizes some of the Fire Economics Assessment Team's fire expenditure information, which has been updated to include expenditures from the FY 1998 fire season.

Methods

This assessment focused on fire management expenditures under the control of the Fire and Aviation Management (FAM) staff in Washington, D.C. (WO) within the Forest Service. These expenditures are an understatement of total fire management expenditures on National Forests or for the Forest Service for two main reasons. First, FAM is not the only area within the Forest Service performing fire management activities. For example, timber managers conduct fuels improvement by using brush-disposal funds collected from timber sales. Second, agencies other than the Forest Service fight fires on National Forests, for which partial or no reimbursement is made. For example, when military personnel fight fire on National Forests, the Forest Service reimburses for expenditures above basic expenses only. When a USDI agency, such as the Bureau of Land

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Management, fights fire on National Forests, there is no transfer of funds. Similarly, there is no transfer of funds when Forest Service personnel fight fire on USDI lands.

Information on fire expenditures attempted to describe expenditures under control of FAM for Forest Fire Preparedness (formerly called Fire Protection) and Fire Operation activities (formerly called Fighting Forest Fires). This was done over time (FY 1970-98) and space (by Forest Service regions) in both nominal and constant 1998 dollars. We focused on standard Forest Service administrative regions: Northern Region (R-1), Rocky Mountain Region (R-2), Southwestern Region (R-3), Intermountain Region (R-4), Pacific Southwest Region (R-5), Pacific Northwest Region (R-6), Southern Region (R-8), Eastern Region (R-9), and the Alaska Region (R-10); the Washington Office and affiliated units were designated as R-13+. Analysis of data was limited to simple descriptive statistics (e.g., mean and standard deviation) and regression analysis of time series to determine the efficacy of a compound growth trend.

Data Collection

Information about fire expenditures came from several sources, but all basically derived from official Forest Service accounting records, the "statement of obligations" produced through the National Finance Center. Data collected can be divided into aggregates of years. FY 1970-88 data were mainly to have been provided through the Forest Service WO Fiscal and Accounting Services (FAS) staff. When available, those records were copied from archived original records stored in the WO. Once received, appropriate information was entered into data-entry and data accumulation spreadsheets developed by Rocky Mountain Research Station (RMRS) personnel. In several cases, FY 1983-88 records did not exist and had to be obtained through an iterative process of contacting regional-level fiscal personnel. FY 1989-98 information was provided electronically by the WO-FAM staff, with the assistance of regional fiscal management specialists. Information received was in the form of electronic files, which were converted to the RMRS spreadsheet format.

Data Structure

The format of fire expenditure records has changed over time. Expenditure categories (currently referred to as "work activities") became more and less detailed, and budget accounts (currently referred to as "fund codes") varied between 1- and 2-year appropriations and were controlled by Fire and Aviation Management and/or Timber Management. General Administration (GA) expenditures were included in fire management appropriations in some years and appropriated separately in others. Nevertheless, this study always focused on two broad appropriations: Fire Preparedness and Fire Operations.

Changes in the accounting system required construction of a "cross-walk" to ensure uniformity and consistency from year to year (*table 1*). Specifically, personnel from RMRS and WO-FAM developed the crosswalk for FY 1994-98; WO-FAM developed FY 1989-93; and RMRS, WO-FAS and R1-FAS developed FY 1970-88. Because the content and specificity of work activities changed over time, they were aggregated into broad categories:

- Fire Preparedness: Presuppression
 - Fuels
 - Reimbursable expenses
 - Other

- Fire Operations:
 - Suppression
 - Rehabilitation
 - Severity
 - Economic efficiency
 - Fuels
 - Reimbursable expenses
 - Other

For example, fund codes pertaining to Fire Preparedness were 002P&M (protection and maintenance) in FY 1970 (then referred to as appropriation codes) and 701FP (fire protection) in FY 1987. Similarly, work activity codes 101 and 102 contained presuppression expenditures in FY 1970 (then referred to as major functions) and 102 and 111 in FY 1987. The broad categories did not always exist (*table 1*). For example, economic efficiency began with FY 1993; severity began with FY 1987; rehabilitation began with FY 1977; and fuels improvement was distinguished from general presuppression expenditures in FY 1977. Reimbursable expenses are expenses initially paid for by the Forest Service but are later reimbursed by another agency, most notably a state fire-fighting agency; as such they are only temporary expenses and are shown but not included in totals.

Missing Data and Verification

Unfortunately, available accounting records were not always complete and our attempts to use other data sources were not always successful. As a result, in some instances, RMRS personnel estimated fire expenditure data. In many cases, the process of estimating missing data was linked to data verification.

Fire expenditure data were verified both internal to data collection and by external sources. Internally, statement of obligation records came in two formats. In the fund code by work activity (e.g., BUDG4V-3), the statement of obligation showed a fund code total which could be used to verify that data had been correctly entered. In the work activity by fund code (e.g., BUDG4V-5) format, there was no fund code "check total," and we could only inspect data entries for errors; if we could detect that work activity information was missing, they were treated as missing, and regional personnel (both fiscal and fire) were contacted to secure needed records. External verification came from a variety of sources, records, and reports.

Even after extensive efforts to secure all needed data, some could not be secured. We were able to obtain virtually all data for R-1, R-2, and R-3 and most data for R-4, R-6, R-8, R-9, and R-10. R-5 and R-13 (the WO) had the most missing data, with R-13 being, by far, the worst. Missing data were specified in four ways. First, some missing values could be deduced, as when the preceding and succeeding values for a particular work activity was zero. Second, some fund code totals (e.g., R-5 fire operations in FY 1980) were estimated by assuming the same pattern of change as in adjacent regions (e.g., R-3, R-4, and R-6 for missing R-5 values), or by assuming a percentage share for the missing year (e.g., R-6 fire protection expenditures in FY 1981 and FY 1982 were assumed to be 6 percent of the national total because they were that in FY 1980 and FY 1983). Third, in some cases all data were known, except for the missing observation; in that case, the missing observation was deduced as the residual. This approach was used extensively for R-13 (WO), for which there was virtually no expenditure information from FY 1980 through FY 1988. Fourth, in FY 1998, R-6 and R-10 were "pilot" sites for testing the proposed Federal Financial Information System (FFIS), but HIS did not perform adequately and could not provide expenditure information at the work activity level. Consequently, we apportioned total FY 1998 expenditures to work activities based on the FY 1997 distribution of expenditures by work activities.

Table 1- Fund codes and work activity codes for classes of wildland fire management expenditures.

Fiscal year	Fire Preparedness (formerly Forest Fire Protection)					Fire Operations (formerly Fighting Forest Fires)							
	Work activity classes					Work activity classes							
	Fund codes	Presuppression	Fuels	Reimbursable Expenses	Other	Fund codes	Suppression	Rehabilitation	Severity	Economic efficiency	Fuels	Reimbursable Expenses	Other
1970	002P&M	101, 102	---	312,313	320	003FFF	101, 102, 103	-	---	---	---	312, 313	---
1971	102P&M	101,102	---	312,313	320	103FFF	101, 102, 103	-	---	---	---	312, 313	---
1972	202P&M	101,102	---	312,313	320	203FFF	101, 102, 103	-	---	---	---	312, 313	---
1973	302P&M	101,102	---	312,313	320	303FFF	101, 102, 103	-	---	---	---	312, 313	---
1974	402P&M	101,102	---	312,313	320	403FFF	101, 102, 103	-	---	---	---	312, 313	315
1975	502P&M	101,102	---	312,313	320	503FFF	101, 102, 103	-	---	---	---	312, 313	315
1976	602	101,102	---	312,313	320	603	101, 102, 103	-	---	---	---	312, 313	180, 315
1976TQ ¹	102	101,102	---	312,313	320	103	101, 102, 403	-	---	---	---	312, 313	180, 315
1977	701	111 to 114, 116, 920s, 930s	115	312,313	173,180,960+	703	102, 111 to 116	094	---	---	---	312, 313	180
1978	801	111 to 114, 116, 920s, 930s	115	312,313	173,180,960+	803	102, 111 to 116	094	---	---	---	312, 313	180
1979	901FM	102, 110 to 114, 116, 920s, 930s		312,313	173, 180, 311, 316,960+	903FFF	102, 110 to 116	094	---	---	---	312, 313	180, 316
1980	001FFP	102, 111 to 114	115	312,313	311,316	003FFF	102	092	---	---	---	312, 313	316
1981	101FFP	102, 111 to 114	115	312,313	311,316	103FFF	102	092	---	---	---	312, 313	316
1982	201FFP	102, 111 to 114	115	312,313	311,316	203FFF	102	092	---	---	---	312, 313	316
1983	301FP	102, 111 to 114	115	312,313	311,316	303FFF	102	092	---	---	---	312, 313	316
1984	401FP	102, 111 to 114	115	312,313	311,316	403FFF	102	092	---	---	---	312, 313	316
1985	501FP	102, 111 to 114	115	312,313	311,316	503FFF	102	092	---	---	---	312, 313	316
1986	601FP	102, 111 to 114	115	312,313	311,316	603FFF	102	092	---	---	---	312, 313	316
1987	701FP	102,111	115	312,313	311	703FFF	102	092	111	---	---	312, 313	316
1988	8NFAF	PF11s, PF12	PF2s	TSs	ETs, GMs, MLs, PLs	8NFFF8	PF12s	FWs	PF1ls	---	---	TSs	ATs, TSs
						8NFFF9	PF12s	FWs	PF1ls	---	---	TSs	ATs, TSs
1989	9NFAF	PF1ls, PF12	PF2s	TSs	ETs, GMs, MLs, PLs	9NFFF9	PF12s	FWs	PF11s	---	---	TSs	ATs, TSs
						9NFFF0	PF12s	FWs	PF1ls	---	---	TSs	ATs, TSs
1990	0NFAF	PF11s, PF12	PF2s	TSs	Others	0FFFS0	PF12	FWs, ATs, LTs	PF1ls	---	---	TSs	Others
	0FFFP	PF11s, PF12	PF2s	TSs	Others	0FFFS	PF12		PF1ls	---	---	TSs	Others
1991	FFFP	PF11s, PF12	PF2s	TSs	Others	FFFS	PF12	FWs, ATs, LTs	PF1ls	---	---	TSs	Others
1992	FFFP	PF11s, PF12	PF2s	TSs	Others	FFFS	PF12	FWs, ATs, LTs	PF1ls	---	---	TSs	Others
						EFFS	PF12	FWs, ATs, LTs	PF11s	---	---	TSs	Others
1993	FFFP	PF1ls, PF12	PF2s	TSs	Others	EFFS	PF12	FWs, ATs, LTs	PF1ls	PF114	---	TSs	Others
1994	FFFP	PF1ls, PF12	PF2s	TSs	Others	EFFS	PF12	FWs, ATs, LTs	PF1ls	PF114	---	TSs	Others
1995	FFFP	PF1ls, PF12	PF2s	TSs	Others	EFFS	PF12	FWs, ATs, LTs	PF1ls, PF115	PF114	---	TSs	Others
1996	WFPR	PF11s, PF12	PF2s	TSs	Others	WFSU	PF12	FWs, ATs, LTs	PF1ls, PF115	PF114	---	TSs	Others
1997	WFPR	PF11s, PF12	PF2s	TSs	Others	WFSU	PF12	FWs, ATs, LTs	PF1ls, PF115	PF114	---	TSs	Others
1998	WFPR	PF11s, PF12	---	TSs	Others	WFSU	PF12	FWs, ATs, LTs	PF11s, PF115	PF114	---	TSs	Others

¹ TQ = transition quarter, July-September, 1976

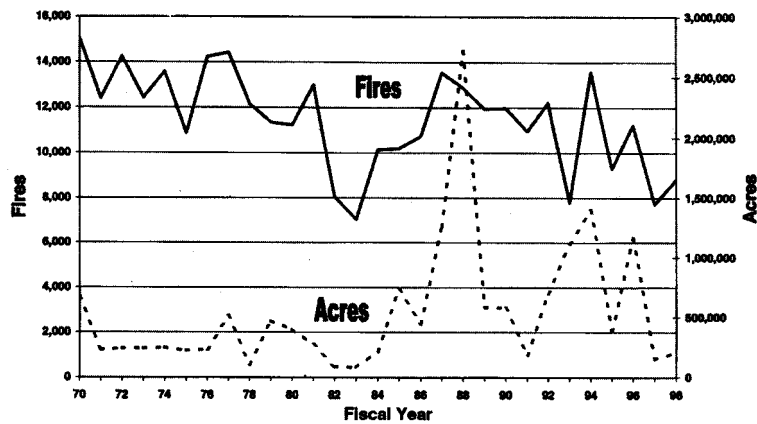


Figure 1

Number of fires and acres burned, FY 1970-98, by year.

Results

FY 1994 did not have the largest number of fires, nor were the most acres burned. Over the FY 1970-98 period, the largest number of fires occurred in FY 1970, when there were more than 15,000 ignitions; FY 1994 ranks fifth, with 13,575 fires (*fig. 1*). Over time, the number of fires has been dropping. The average number of fires annually during the first early years (FY 1970-74) was 13,542, which decreased to an average of 10,122 fires per year during the later years (FY 1994-98). The annual number of fires showed a statistically significant ($p = 0.00$) compound growth rate of about -1.2 percent annually. The most acres burned in FY 1988, when more than 2.7 million acres burned; FY 1994 ranked second, with almost 1.4 million acres. Although the number of fires has been declining, the acreage burned has been increasing. During FY 1970-74, an average of 325,106 acres was burned annually, and by FY 1994-98 the annual average had risen to 661,860 acres. The annual acres burned showed a statistically significant ($p = 0.09$) compound growth rate of about 3.3 percent per year. However, FY 1994 is important because it ranks first in expense; it was the most expensive year on record, exceeding the previous record (FY 1988) by 56.9 percent. Fire management expenditures in FY 1994 prompted this assessment.

Overall Expenditures

This assessment of fire management expenditures covers the time period FY 1970-98. Over this period, the Forest Service spent about \$9.6 billion on fire management activities. Fire management expenditures amounting to \$56 million in FY 1970 rose to nearly \$1 billion by FY 1994, a seventeenfold increase (*fig. 2*). The FY 1970-74 annual average of \$100 million rose to an annual average of \$659 million during the period FY 1994-98. Annual expenditures rose at a statistically significant ($p = 0.00$) compound growth rate of 7.4 percent annually. The infamous 1988 fire season was expensive (\$592 million), but not nearly as expensive as the record year of FY 1994, when \$944 million were spent.

Measuring total fire management expenditures in constant 1998 dollars adjusts for inflation, which holds the purchasing power of money constant (*fig. 2*). In

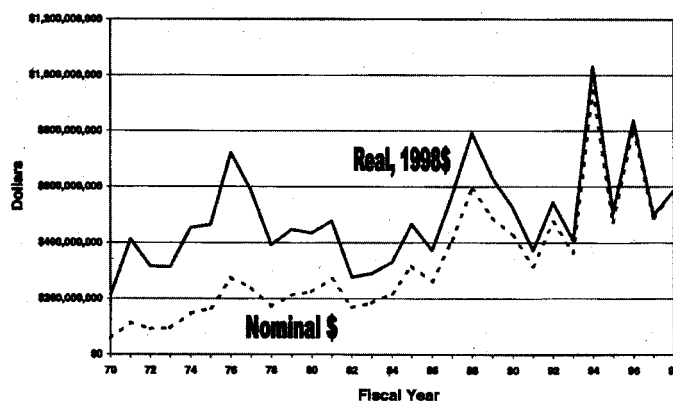


Figure 2

Total fire management expenditures, FY 1970-98, by year.

constant dollars, FY 1994 at \$1.032 billion was still the record year, followed by FY 1988 at \$793 million, and FY 1976 (a 15-month year) at \$721 million. Though highly erratic, real, total fire management expenditures from FY 1970-98 show a statistically significant ($p = 0.01$) compound growth rate of 2.1 percent annually, about one-third the rate of nominal expenditures. Even with FY 1994 removed from the time series of real, total expenditures, the trend remains statistically significant ($p = 0.01$), but the compound growth rate drops to 1.8 percent annually. On the basis of constant 1998 dollars, about \$14.3 billion were spent on fire management activities for FY 1970-98, an amount 49.0 percent greater than when measured in current-year dollars.

Fire management expenditures are generally divided into two broad categories: Forest Fire Preparedness and Fire Operations. The specific activities accomplished under each category are referred to as "work activities." For example, PF1142 is the activity code used for work related to fire detection. We grouped work activities into aggregates, mainly because there are too many to meaningfully assess individually. Presuppression includes expenditures for preventing, detecting, dispatching, planning, training, overhead, and staffing the initial attack organization. The initial attack organization includes recruiting, hiring, training, personnel compensation, equipment, and other such resources. Fuels improvement refers to action taken to reduce fire hazard, such as through prescribed burning. Suppression expenditures refer to those incurred after a natural fire has been declared a "wildfire" or when Presuppression funding is inadequate to cover all initial attack expenses. Emergency fire Rehabilitation expenditures prevent additional damage resulting from suppression actions by performing activities such as repairing trails and fences, water baring fire lines, and repairing drainage ditches. Severity expenditures are for emergency presuppression actions needed because of higher-than-average fire danger and potential fire severity. Economic efficiency expenditures are used to provide non-emergency presuppression capability, resulting from an imbalance between Preparedness and Operations appropriations. Reimbursable Expenses are only temporary expenses, because they represent amounts that other organizations (e.g., state agencies) pay the Forest Service for services rendered (Reimbursable Expenses are shown for information only and are not included in totals). The Other categories consist of work activities that did not clearly fit other categories, such as law enforcement.

Overall expenditures (nominal dollars) for the Fire Preparedness and Fire Operations fund codes, and the aggregates of work activities within each, were determined (*table 2*). Expenditures in constant 1998 dollars were also determined and should be used to identify changes in "real" fire management expenditures (*table 3*). Expenditures not shown (i.e., "---") represent situations where the work activity aggregate was not functional. For example, Severity begins in FY 1987; it did not exist in prior years. Similarly, appropriations for Fuels did not begin until FY 1977 and in FY 1998 fuel treatments were funded under the fire Operations fund code, instead of Preparedness.

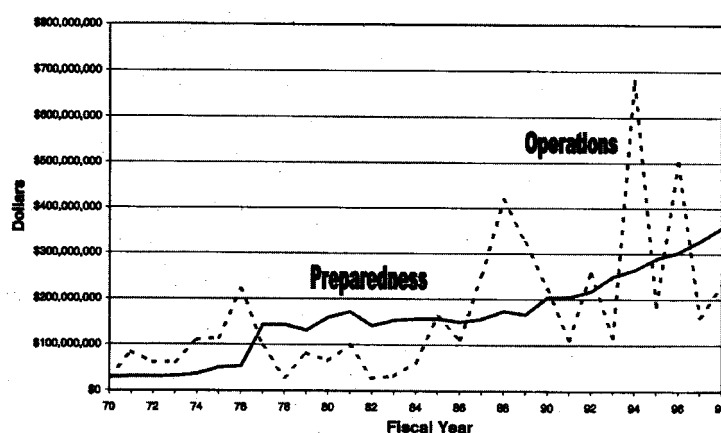
The historical level of nominal expenditures in both categories were determined (*fig. 3*). Because Severity expenditures in FY 1987-98 and Economic Efficiency expenditures in FY 1993-95 were intended to supplement Presuppression expenditures, they were added to Fire Preparedness totals and subtracted from the Fire Operations totals. Several features stand out. First, the expenditures appear somewhat equivalent in magnitude, although (adjusted) Fire Operations expenditures are far more erratic. Indeed, over the FY 1970-98 period, annual Fire Operations expenditures averaged about \$169.0 million, only 4.9 percent greater than those for Fire Preparedness, which averaged \$161.1 million annually. However, the variability of Fire Operations expenditures (measured by the standard deviation) was 64.9 percent greater than those for Fire Preparedness. Second, although Fire Operations expenditures accounted for 51.2 percent of the overall total, the mix has been changing. In the early years, Fire Fire Preparedness

Table 2--Forest Service wildland fire management expenditures, FY 1970-98, for Fire Preparedness and Fire Operations, by major class of expenditure.

Fire Preparedness										Fire Operations				
Fiscal year	Presuppression	Fuels	Other Reimbursement Total			Suppression	Fuels	Rehabilitation	Severity	Economic Efficiency	Other	Reimbursement	Total	Grand total
1970	\$28,234,106	----	\$63,470	\$4,382,432	\$28,297,576	\$27,425,705	----	----	----	----	\$3,123	\$1,044,519	\$27,428,828	\$55,726,404
1971	30,139,322	----	62,278	4,410,889	30,201,600	82,929,089	----	----	----	----	0	2,388,901	82,929,089	113,130,688
1972	30,194,836	----	130,533	3,469,939	30,325,369	60,508,114	----	----	----	----	0	3,011,878	60,508,114	90,833,483
1973	31,618,290	----	0	3,531,627	31,618,290	62,141,570	----	----	----	----	0	2,039,041	62,141,570	93,759,860
1974	35,864,090	----	0	3,920,551	35,864,090	110,053,738	----	----	----	----	4,740	5,299,819	110,058,478	145,922,569
1975	47,020,132	----	2,923,219	4,114,908	49,943,351	114,479,335	----	----	----	----	16,305	4,311,228	114,495,641	164,438,992
1976	38,354,111	----	0	7,607,043	38,354,111	150,803,587	----	----	----	----	17,619	2,829,235	150,821,206	189,175,316
76TQ	13,781,468	----	782,350	1,610,810	14,563,818	70,200,929	----	----	----	----	8,457	1,628,897	70,209,386	84,773,204
1977	111,254,555	\$5,368,327	26,400,244	1,238,337	143,023,126	95,435,588	----	\$695,522	----	----	13,218	7,140,402	96,144,328	239,167,454
1978	104,541,207	11,528,545	26,968,773	983,107	143,038,524	27,683,921	----	630,858	----	----	127,900	2,630,034	28,442,679	171,481,203
1979	115,288,501	14,666,134	1,028,759	863,706	130,983,394	80,339,053	----	315,594	----	----	366,960	4,509,465	81,021,606	212,005,000
1980	138,338,458	21,088,634	113,287	1,588,200	159,540,378	63,375,264	----	1,365,721	----	----	4,242	4,444,461	64,745,227	224,285,605
1981	151,709,352	19,549,933	81,089	1,625,186	171,340,374	97,822,618	----	1,233,216	----	----	2,673	7,094,653	99,058,508	270,398,881
1982	124,894,897	16,297,431	45,486	1,652,115	141,237,814	27,158,985	----	102,785	----	----	407	2,563,519	27,262,178	168,499,992
1983	135,081,899	17,833,106	28,003	1,814,343	152,943,008	31,803,617	----	126,220	----	----	244	3,370,927	31,930,081	184,873,088
1984	139,024,025	17,180,623	23,254	1,585,927	156,227,902	62,011,053	----	215,743	----	----	514	4,036,845	62,227,310	218,455,212
1985	141,477,807	15,030,631	9,412	1,799,915	156,517,850	160,473,143	----	1,018,252	----	----	11,721	5,197,209	161,503,116	318,020,966
1986	140,804,355	8,545,330	21,647	1,625,160	149,371,331	110,252,540	----	1,371,391	----	----	1,405	3,725,007	111,625,335	260,996,666
1987	145,674,975	9,499,856	17,343	1,619,727	155,192,175	252,402,013	----	622,714	\$631,523	----	1,403	7,162,062	253,657,652	408,849,827
1988	150,798,495	6,685,323	4,965,681	1,438,410	162,449,499	413,603,415	----	5,021,616	10,995,389	----	-10,678	12,948,665	429,609,741	592,059,240
1989	144,755,945	6,522,766	7,793,121	23,011	159,071,832	317,762,959	----	6,628,811	7,280,089	----	980	7,932,637	331,672,839	490,744,671
1990	158,824,765	7,887,609	9,617,165	490,492	176,329,539	219,750,976	----	2,409,328	27,341,672	----	0	4,145,530	249,501,976	425,831,515
1991	162,674,056	7,835,434	10,213,793	1,195,858	180,723,283	109,938,530	----	1,072,363	23,408,707	----	12,188	1,317,995	134,431,789	315,155,071
1992	169,620,330	7,451,460	10,692,499	760,533	187,764,290	254,825,229	----	1,903,222	29,160,879	----	13,910	4,933,584	285,903,239	473,667,529
1993	164,620,006	12,362,925	9,902,220	2,079,214	186,885,150	108,512,905	----	7,524,319	3,400,296	\$58,713,436	13,821	1,931,675	178,164,777	365,049,927
1994	141,293,264	11,465,698	33,614,071	2,202,217	186,373,033	667,557,238	----	9,505,075	6,225,922	71,624,391	3,007,902	4,605,170	757,920,528	944,293,562
1995	105,486,062	16,643,994	37,175,091	2,654,180	159,305,147	167,660,724	----	12,768,948	4,778,848	125,058,587	4,154,677	8,209,433	314,421,785	473,726,931
1996	219,978,489	19,407,893	46,870,427	1,649,433	286,256,809	493,420,582	----	5,505,429	16,304,408	----	2,561,468	7,032,980	517,791,886	804,048,695
1997	238,639,552	28,164,150	56,156,301	3,186,159	322,960,003	151,326,227	----	5,477,215	4,549,525	----	4,432,969	12,274,056	165,785,936	488,745,939
1998	247,458,613	----	65,410,239	3,421,353	312,868,852	219,051,395	\$39,807,275	1,370,710	3,887,661	----	8,998,660	65,160,226	273,115,701	585,984,552

Table 3--Forest Service wildland fire management expenditures, FY 1970-98, in 1998 dollars, for Fire Preparedness and Fire Operations, by major class of expenditure.

Fire Preparedness						Fire Operations								
Fiscal year	Presuppression	Fuels	Other	Reimbursement	Total	Suppression	Fuels	Rehabilitation	Severity	Economic Efficiency	Other	Reimbursement	Total	Grand total
1970	\$108,370,668	----	\$243,617	\$16,821,043	\$108,614,286	\$105,267,790	----	----	----	----	\$11,987	\$4,009,165	\$105,279,777	213,894,063
1971	110,022,412	----	227,343	16,101,776	110,249,754	302,729,384	----	----	----	----	0	8,720,590	302,729,384	412,979,138
1972	105,210,273	----	454,828	12,090,583	105,665,101	210,833,248	----	----	----	----	0	10,494,526	210,833,248	316,498,349
1973	105,529,028	----	0	11,787,138	105,529,028	207,403,358	----	----	----	----	0	6,805,491	207,403,358	312,932,385
1974	111,624,673	----	0	12,202,462	111,624,673	342,535,179	----	----	----	----	14,753	16,495,347	342,549,933	454,174,606
1975	132,686,630	----	8,249,065	11,611,904	140,935,695	323,050,505	----	----	----	----	46,012	12,165,901	323,096,517	464,032,212
1976	100,942,045	----	0	20,020,553	100,942,045	396,891,547	----	----	----	----	46,370	7,446,106	396,937,917	497,879,962
76TQ	36,270,678	----	2,059,023	4,239,400	38,329,700	184,757,909	----	----	----	----	22,258	4,287,004	184,780,166	223,109,867
1977	272,108,223	\$13,129,943	64,570,152	3,028,746	349,808,318	233,417,933	----	\$1,701,119	----	----	32,330	17,464,114	235,151,382	584,959,700
1978	238,856,281	26,340,477	61,618,390	2,246,208	326,815,148	63,252,364	----	1,441,387	----	----	292,226	6,009,115	64,985,977	391,801,125
1979	243,283,303	30,948,668	2,170,900	1,822,604	276,402,871	169,532,520	----	665,971	----	----	774,363	9,515,933	170,972,854	447,375,725
1980	268,089,103	40,868,121	219,540	3,077,807	309,176,764	122,816,302	----	2,646,661	----	----	8,220	8,613,018	125,471,183	434,647,947
1981	267,634,680	34,488,580	143,051	2,867,035	302,266,310	172,571,597	----	2,175,551	----	----	4,716	12,515,874	174,751,864	477,018,174
1982	205,793,542	26,853,828	74,949	2,722,246	232,722,319	44,750,778	----	169,363	----	----	671	4,223,997	44,920,812	277,643,130
1983	212,753,066	28,087,019	44,104	2,857,577	240,884,189	50,090,479	----	198,796	----	----	384	5,309,187	50,289,658	291,173,847
1984	210,811,509	26,052,138	35,262	2,404,849	236,898,910	94,031,544	----	327,145	----	----	779	6,121,341	94,359,468	331,258,378
1985	207,387,654	22,032,907	13,796	2,638,436	229,434,358	235,232,291	----	1,492,622	----	----	17,181	7,618,417	236,742,094	466,176,452
1986	200,689,879	12,179,746	30,853	2,316,357	212,900,478	157,144,066	----	1,954,658	----	----	2,002	5,309,290	159,100,726	372,001,204
1987	201,798,398	13,159,815	24,025	2,243,750	214,982,239	349,643,593	----	862,623	\$874,827	----	1,944	9,921,351	351,382,987	566,365,226
1988	201,884,759	8,950,121	6,647,913	1,925,702	217,482,792	553,720,549	----	6,722,797	14,720,315	----	-14,296	17,335,306	575,149,366	792,632,158
1989	185,929,818	8,378,079	10,009,769	29,557	204,317,666	408,146,341	----	8,514,286	9,350,813	----	1,259	10,188,969	426,012,698	630,330,364
1990	195,875,351	9,727,628	11,860,654	604,914	217,463,633	271,014,408	----	2,971,375	33,719,928	----	0	5,112,598	307,705,712	525,169,345
1991	192,362,280	9,265,410	12,077,824	1,414,103	213,705,515	130,002,454	----	1,268,071	27,680,826	----	14,412	1,558,531	158,965,763	372,671,278
1992	194,859,835	8,560,238	12,283,543	873,700	215,703,616	292,743,223	----	2,186,421	33,500,018	----	15,980	5,667,701	328,445,641	544,149,258
1993	184,251,230	13,837,225	11,083,077	2,327,164	209,171,532	121,453,259	----	8,421,607	3,805,788	\$65,715,116	15,469	2,162,031	199,411,239	408,582,771
1994	154,411,816	12,530,246	36,735,012	2,406,685	203,677,075	729,537,439	----	10,387,586	6,803,975	78,274,448	3,287,175	5,032,743	828,290,623	031,967,698
1995	112,393,236	17,733,835	39,609,297	2,827,975	169,736,368	178,639,065	----	13,605,053	5,091,765	133,247,361	4,426,724	8,746,982	335,009,967	504,746,335
1996	229,091,912	20,211,936	48,812,208	1,717,767	298,116,057	513,862,356	----	5,733,512	16,979,878	----	2,667,586	7,324,347	539,243,331	837,359,388
1997	243,169,343	28,698,754	57,222,245	3,246,638	329,090,342	154,198,660	----	5,581,182	4,635,883	----	4,517,114	12,507,039	168,932,840	498,023,181
1998	247,458,613	----	65,410,239	3,421,353	312,868,852	219,051,395	\$39,807,275	1,370,710	3,887,661	----	8,998,660	65,160,226	273,115,701	585,984,552

**Figure 3**

Fire preparedness and fire operations expenditures, FY 1970-98, by year. Preparedness includes Operations and excludes Economic Efficiency, Severity, and Fuels.

Operations expenditures accounted for 68.7 percent of the total, but only 53.3 percent in later years. Third, it is not clear on a yearly basis which category has the larger expenditure. In about half of the years (both recent and in the past), Fire Preparedness expenditures exceeded those for Fire Operations. Fourth, both Preparedness and Operations expenditures demonstrated statistically significant compound growth rates, 8.7 percent ($p = 0.00$) for Fire Preparedness expenditures and 6.6 percent ($p = 0.00$) for Fire Operations expenditures.

The increase in fire management expenditures (1998 dollars) was not uniform within fire activities or among regions (*table 4*). Overall, annual average expenditures increased by almost \$350 million per year, from the FY 1970-74 average of \$342 million to an average of \$691 million during FY 1994-98. Overall, expenditure changes in Fire Operations accounted for about 55.8 percent of all changes and expenditure changes in R-5 (California) and WO+ accounted for 25.7 percent and 20.9 percent of the changes, respectively. The largest, single area of change involved Fire Operations by the WO+, which accounted for 15.8 percent of the total change. WO+ expenditures include expenses of operating the WO-FAM staff, funding research (Missoula, Montana and Riverside, California) and development (Missoula, Montana and San Dimas, California) projects, operating the National Advances Resource and Technology Center (Marana, Arizona) for advanced fire management training, and supporting the Forest Service portion of the National Interagency Fire Center (Boise, Idaho) which provides national contracts for air tankers, helicopters, etc. Almost one-third of Preparedness increases was accounted for by expenditures in R-5, which also accounted for 14.0 percent of the total increase. Expenditure changes in R-9 (the Eastern) and R-10 (Alaska) accounted for the smallest portion of Fire Preparedness and Fire Operations changes.

Table 4- Total and percentage distribution of Fire Preparedness and Fire Operations expenditure changes, FY 1970-74 average relative to FY 1994-98 average, in 1998 dollars.

Forest Service region	Expenditure change			Percent distribution		
	Preparedness	Operations	Total	Preparedness	Operations	Total
R-1	\$12,292,697	\$11,894,431	\$24,187,127	0.04	0.03	0.07
R-2	6,831,555	7,783,118	14,614,673	0.02	0.02	0.04
R-3	19,313,650	9,421,801	28,735,451	0.06	0.03	0.08
R-4	14,672,599	22,375,734	37,048,333	0.04	0.06	0.11
R-5	48,997,988	40,929,272	89,927,260	0.14	0.12	0.26
R-6	25,125,159	14,325,897	39,451,056	0.07	0.04	0.11
R-8	8,062,686	23,093,658	31,156,344	0.02	0.07	0.09
R-9	754,330	6,514,414	7,268,743	0.00	0.02	0.02
R-10	551,525	3,515,647	4,067,171	0.00	0.01	0.01
WO+	17,758,982	55,305,381	73,064,363	0.05	0.16	0.21
Total	\$154,361,170	\$195,159,352	\$349,520,523	0.44	0.56	1.00

Fire Preparedness

Not only did nominal Fire Preparedness (including Severity and Economic Efficiency) expenditures rise dramatically during the study period, those expenditures also increased when expressed in 1998 dollars (*fig. 4*). In constant dollars, (adjusted) Fire Preparedness expenditures rose at a statistically significant ($p = 0.00$) compound rate of 3.4 percent annually, about one-third the rate expressed in nominal dollars. In constant dollars, those Fire Preparedness expenditures accounted for 50.8 percent of all fire management expenditures in FY 1970, dropped to a minimum of 19.3 percent in FY 1976, rose to a maximum of 83.8 percent in FY 1982, and decreased to 60.8 percent in FY 1998.

Presuppression

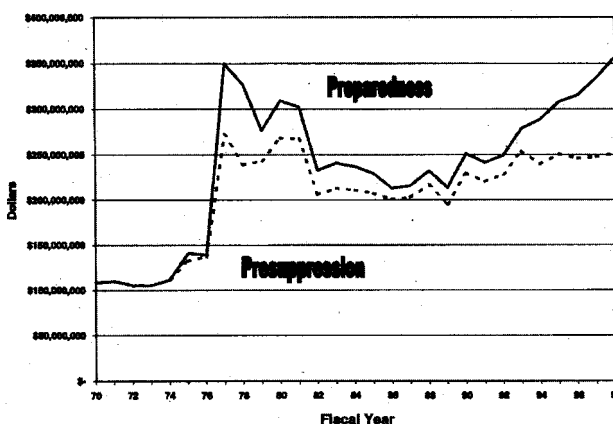
Expenditures for Presuppression have dominated Fire Preparedness expenditures (*fig. 4*). During the FY 1970-98 time period, Presuppression (including Severity and Economic Efficiency) accounted for 86.8 percent of all Preparedness expenditures, averaging about \$204 million (1998 dollars) over this period. In fact, these (adjusted) Presuppression expenditures rose at a statistically significant ($p = 0.00$) compound rate of 2.8 percent annually over the time period. However, the most notable aspect of Presuppression expenditures (and hence Fire Preparation expenditures) is the sharp rise in FY 1977. This rise reflected increased fire presuppression appropriations after the large fires of 1967, 1970, and 1972, and the 1972 fire re-planning effort, which recommended increased presuppression resources. In FY 1972, the "10:00 A.M." policy was replaced by "appropriate suppression response" for escaped fires. In FY 1978, this was extended to initial attack. Pre-attack planning probably caused expenditure increases. Considering the FY 1977-98 period only, neither Presuppression nor Fire Preparation expenditures displayed a statistically significant trend.

Though labeled "presuppression," some expenditures contained in Presuppression are actually for suppressing forest fires. For example, the work activity (PF12) covering fire suppression constituted 2.2 percent of the Presuppression expenditures for the period FY 1991-95. This situation results from fiscal and accounting conventions. Fire suppression activities are charged to Presuppression for the base salary (the first 8 hours) of Preparedness-funded, initial-attack personnel. Overtime, hazard pay, and any other expenses not included in the Preparedness budget are charged to Suppression in the Operations budget. Additionally, if backup personnel replace Preparedness-funded presuppression personnel at their home unit, backup personnel expenses are charged to Presuppression and all personnel expenses for the original presuppression personnel are charged to Operations-Suppression.

Fuels Improvement

Expenditure information for Fuels Improvement begins in FY 1977 (*fig. 5*); but that does not mean that activities to improve fuels did not take place before FY 1977. Rather, before FY 1977 Timber Management staffs controlled all

Figure 4
Fire preparedness and presuppression expenditures, FY 1970-98, by year. Preparedness includes Economic Efficiency, Severity, and Fuels while Presuppression includes Economic Efficiency and Severity.



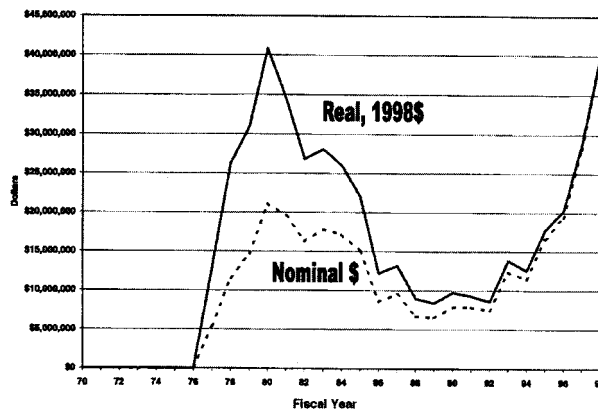


Figure 5
Fuel treatment expenditures, FY 1970-98, by year.

expenditures related to Fire Preparedness, not FAM staffs. Because Timber Management staffs also conduct fuels improvement activities not related to fire protection (e.g., slash reduction in timber sales), the accounting system could not distinguish between timber-related fuels improvement from fire management fuels improvement. Starting with the new Federal fiscal year configuration in FY 1977, Fire Preparedness appropriations came under the control of FAM.

Expenditures on fuel treatments have been extremely variable over the period FY 1977-98. They rose sharply during the decade of the 1970's (*fig. 5*). In fact when expressed in constant 1998 dollars, expenditures reach a peak in FY 1980 of \$40.9 million, exceeding those of \$39.8 million in FY 1998. Fuel treatment expenditures steadily decreased during the decade of the 1980's, reaching a low of about \$9 million (1998 dollars) at the end of the decade. Fuel treatment expenditures generally increased during the decade of the 1990's. Nevertheless, average annual expenditures during the 1990's of \$17.8 million were still 19.4 percent below the annual average of \$22.1 million during the 1980's. As a result of this extreme variability, no statistical trend in fuel treatment expenditures can be detected over the period FY 1977-98, for either nominal or constant dollars. However, during the 1990's, annual expenditures on fuel treatments (1998 dollars) rose at a statistically significant ($p = 0.00$) compound rate of 20.1 percent annually.

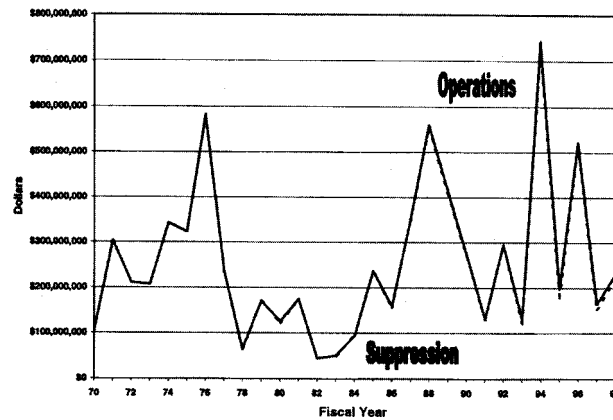
Fire Operations

Expenditures related to Fire Operations were far more difficult to evaluate at the level of work activity aggregates than were Fire Preparedness expenditures. The main reason for this is that only one aggregate, Suppression, existed over the entire FY 1970-98 time period. Rehabilitation was formally recognized in FY 1977; Severity began in FY 1987; Economic Efficiency began in FY 1993 and ended in FY 1995; and Fuels began in FY 1998. In the case of Rehabilitation, the appropriate work activity code did not exist before FY 1977; thus, any rehabilitation work was charged to another code. The work activity code used to measure Severity existed before FY 1987 but could not be used with Fire Operations appropriations. The work activity code used for Economic Efficiency existed in FY 1991 but was little used until FY 1993 when it was designated for use with Economic Efficiency.

As with nominal dollars, expenditures for Fire Operations (excluding Severity, Economic Efficiency, and Fuels) measured in constant 1998 dollars have been extremely erratic from FY 1970-98 (*fig. 6*). The same is true for Suppression expenditures. Indeed, because Suppression expenditures accounted for 98.6 percent of (adjusted) Fire Operations expenditures from FY 1970-98, the two expenditure series cannot be distinguished, and will be treated as one series (*fig. 6*). *Figure 3* displayed annual (adjusted) Fire Operations expenditures measured in nominal dollars and a statistically significant compound growth rate of 6.6 percent annually. A completely different picture is portrayed in constant 1998 dollars. In constant dollars, (adjusted) Fire Operations expenditures averaged \$254.5 million during the 1970's, dropped to \$221.3 million during the

Figure 6

Fire operations and suppression expenditures, FY 1970-98, by year. Operations exclude Economic Efficiency, Severity, and Fuels.



1980's, and increased to \$298.4 million during the 1990's. The intervening years were highly volatile, with the most expenditures in FY 1994 (\$743 million) exceeding the least expenditures in FY 1982 (\$45 million) by a factor of sixteen. Not surprisingly, when those annual Fire Operations expenditures are measured in constant 1998 dollars, no statistically significant ($p = 0.38$) trend can be discerned. However, the variability in annual Fire Operations expenditures is increasing. If variability in expenditures (as portrayed by the standard deviation) is indexed at 100 for the 1970's, the 1980's index would be 117, meaning that annual Operations expenditures were about 17 percent more variable during the 1980's than during the 1970's. The 1990's index would be 141, meaning that Operations expenditures during the 1990's were about 41 percent more variable than during the 1970's.

Discussion

There is little doubt that over the period FY 1970-98 the annual number of fires has been decreasing, but at the same time, the number of acres burned and overall fire management expenditures have been increasing. Over that time period, nominal expenditures increased at an annual compound rate of 7.4 percent and real expenditures increased by about 2.1 percent annually. The bulk of expenditure increase was in Fire Operations (formerly called Fighting Forest Fires), which consists mainly of fire suppression expenditures. Although nominal Fire Operations expenditures showed a positive statistical trend, no trend was discernible when annual expenditures were expressed in constant 1998 dollars. However, as might be suspected, Fire Operations expenditures are becoming increasingly variable over time. Expenditures on Fire Preparedness (formerly called Fire Protection) have displayed a positive statistical trend, whether measured in nominal or constant 1998 dollars. Although expenditures on fuel treatments have been increasing recently, they have been so variable over time that no statistical trend could be identified over the FY 1970-98 period. However, expenditures on fuels have risen remarkably during the 1990's.

Expenditure data on fire management are at the same time satisfying and frustrating. We have now developed an extensive time series of detailed fire management expenditure information. The biggest difficulties involved the early years. Many records were unavailable and information had to be developed from a variety of sources. Future data on fire management expenditures should be easily obtained because of modern, electronic accounting systems. However, accounting systems evolve to meet the needs of fire management and financial management. Over time, one challenge will be to maintain enough detailed information so that trends in data series can be evaluated, despite changes in accounting specifics. Another frustration with accounting and budgeting systems is the mixing and movement of work activity aggregates between fund codes.

This can be confusing. For example, Congress appropriates monies for Fire Operations, which is a perfectly legitimate accounting level (*tables 2, 3*). However, in FY 1998 appropriations for Fire Operations included appropriations for fuel treatments, which were previously contained in appropriations for Fire Preparedness. The other frustration results from major changes in the accounting system, such as those currently taking place as the Forest Service attempts to implement the new Federal Financial Information System (FFIS). Effective with FY 2000, FFIS promises to provide more accurate and timely financial information. Hopefully, any problems with the accounting system will be short-lived and allow sustained measurement and monitoring of fire management expenditures.

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Assessing the Risk of Cumulative Burned Acreage Using the Poisson Probability Model¹

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Abstract

Resource managers are frequently concerned that the area burned by wildfire over time will impede achievement of land management objectives. Methods that use the Poisson probability model to quantify that risk are described. The methods require a concise statement of an adverse wildfire outcome and information on fire frequencies and sizes. An example is presented that illustrates use of the risk assessment procedure to quantify the trade-off between burned acreage risk and the cost of a fuels treatment project that reduces risk.

Forest wildfire can pose a significant risk to achieving forest land management objectives. Water quality in municipal watersheds can be threatened by wildfire events. Anadromous fisheries can be endangered by the stream sedimentation resulting from runoff when rainstorms follow a large fire or even a series of smaller fires. Maintaining minimum acceptable levels of a wildlife habitat can also be at risk to the cumulative effects of wildfire. Sustained timber supplies are also at risk to wildfire events. For these reasons resource managers are concerned with the uncertainty posed by wildfire. Their concern centers on both the threat to meeting land management objectives and the costs of wildfire risk management.

Accurately assessing the uncertainty posed by wildfire is frequently quite difficult, particularly if the outcomes of concern involve collections of random events. When adequate data are available, quantitative techniques can help in estimating the probabilities of wildfire outcomes involving joint random events, as has been shown for adverse fire movement (Wiitala and Carlton 1994). These procedures will help reduce the biases that can creep into purely subjective assessments of these probabilities (Cleaves 1994).

This paper describes how probability theory can be used to assess the risk posed by wildfire to achieving resource management objectives. The procedures combine fire size and frequency data with the Poisson probability model to calculate the chance that burned area will exceed some threshold for a given area and period. A hypothetical example is presented that illustrates use of the risk assessment procedure to quantify the trade-off between burned acreage risk and the cost of a fuels treatment project that reduces risk.

Wildfire Risk

The forest wildfire environment is characterized by much randomness. Specific wildfire outcomes are governed by the laws of chance. Resulting cumulative effects can jeopardize achieving resource management objectives. While management opportunities exist to alter the odds of this game of chance, avoiding the game is not possible. Resource managers will always face some level of wildfire risk as defined by the chance of an undesirable wildfire outcome, and not just the chance or probability of a wildfire ignition.

The definition of an undesirable wildfire outcome must be stated in concrete terms relative to the risk of not achieving a resource management objective. For example, a resource objective might be to maintain at least a minimum level of a

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forest habitat judged necessary to sustaining a threatened species. The undesirable outcome could then be defined as a single or set of wildfires causing a habitat loss that violates the minimum acceptable level. Time and magnitude are important dimensions of this definition of an undesirable outcome. With respect to time, the more quickly desired vegetation can be recovered by an ecosystem, the shorter will be the period over which to evaluate risk. For a watershed in which an anadromous fishery is at risk to sedimentation after a wildfire, the risk period is short because a regrowth of vegetation in areas burned may only take a few years. Yet, the risk period would be long where recovery of lost old-growth forest habitat may require decades.

The difference in area between an existing or projected habitat level and a minimum desired level is one yardstick against which to measure the risk posed by wildfire. This difference can be considered an insurance "reserve" or maximum acceptable loss. The collection of random wildfire losses eliminating this reserve defines the undesirable outcome. From a risk assessment standpoint, the question naturally follows "What is the probability of losing the habitat reserve to wildfire?" From a resource management viewpoint, the question is "What resource management or protection actions can be taken to keep the risk within tolerable levels?"

Methods

For most areas of the United States, substantial statistics have been collected on wildfire (Fullman and Brink 1975). The existence of these statistics opens opportunities for analytic approaches to risk assessment. Probability theory and statistics on wildfire frequency and size can be used to calculate the risk of not achieving specific resource management objectives.

Poisson Probability Law and Fire Occurrence

A Poisson random process is characterized by the counting of individual events over space and time (Sundararajan 1991). Many physical random phenomena are found to follow, at least approximately, a Poisson random process (Parzen 1960). Mandallaz and Ye (1997) found the Poisson probability model to characterize well the forest wildfire ignition process.

The simple Poisson model is proposed in this paper as a practical approach to modeling the randomness of wildfire occurrence even if the model is only approximate. Accordingly, where wildfires are estimated to occur in a given area with average frequency μ per unit of time, the probability of observing k fires over time t is given as:

$$\Pr(k; \mu t) = \frac{e^{-\mu t} (\mu t)^k}{k!} \quad [1]$$

in which μt , is called the rate of the Poisson process.

To illustrate the model's use, consider an area that receives on average five fires per year. The chance of receiving seven fires in a given year is:

$$\Pr(7;5) = \frac{e^{-5} (5)^7}{7!} = 0.104 \quad [2]$$

The probability of a compound event, such as receiving seven or more fires in a year, can also be computed. This would most easily be accomplished by calculating probabilities for each outcome in the range zero to six fires. Summing these results would give the probability of receiving six or fewer fires (0.762), and subtracting that value from one would give the probability of receiving seven or more fires in a year (0.238).

Poisson Probability Law and Fire Size

Modeling wildfire frequency with the Poisson probability distribution is a major step toward addressing the risk of adverse wildfire outcomes. Wildfire is a necessary but not sufficient condition of the risk equation. Actual risk arises in regard to the area burned and not necessarily the number of wildfires. Therefore, addressing variability in fire size is as important as addressing variability in wildfire numbers.

Substantial amounts of effort have gone into the search for probability models that characterize variability in wildfire size. An excellent overview of these efforts can be found in Alvarado-Celestino (1992). Variability in wildfire data is represented best by theoretical models that accurately characterize extreme values arising from infrequent but very large fires, such as the Pareto and Weibull continuous probability distributions. Combining one of these models for fire size variability with the Poisson process for fire frequency would result in a compound Poisson probability model presenting significant mathematical and computational challenges. Furthermore, this approach would require sophisticated statistical techniques to identify and estimate the parameters of a probability model best characterizing a particular fire size data set (Alvarado-Celestino 1992).

A more intuitive, mathematically tractable, and less labor intensive tact is offered. It is based on the premise that any continuous distribution used to represent the variability in wildfire size can be approximated by a discrete distribution with a suitable size and number of classes. From historical data an empirical distribution would be constructed from estimates of mean and relative frequency for each fire size class (Pitman 1993). According to the empirical distribution, a fire would have a chance of burning the mean area for a class equal to the estimated relative frequency for the class. Lacking adequate historical data, professional judgment may be required to make these estimates.

Modeling fire size variability with an empirical probability model permits using a valuable theoretical attribute of the Poisson process used to model fire frequency. A Poisson process can be mathematically partitioned into independent Poisson component processes when events of the general process randomly take on attributes of the components (Ross 1989). When this happens, the rate μ of the general Poisson process is apportioned to the component processes on the basis of the relative frequency of events in these component processes. For wildfire occurrence, this mathematical result allows apportioning total fire occurrence among several fire size classes, each following an independent Poisson process. The result opens a door to a practical method for computing the risk of an undesired wildfire outcome, that is, the probability total burned area will exceed some level.

Computation Methods

Computing the probability of interest requires determining wildfire outcomes, estimating individual and joint event probabilities, and aggregating results. For instance, we can hypothesize an area at risk to more than 2,000 burned hectares in a given year. In the area, fires arise in three size classes with frequencies of 6, 2, and 0.5 per annum. Mean fire sizes for these classes are 10, 250, and 1,000 hectares, respectively. Given these three independent fire generating random processes, an adverse outcome would be the joint occurrence of seven, four, and one fires in the respective size classes. This outcome would result in the burning of 2,070 hectares. The probabilities of the individual outcomes from the three fire size classes are given, respectively, in the following equations:

$$\Pr(7;6) = \frac{e^{-6}(6)^7}{7!} = 0.14 \quad [3]$$

$$\Pr(4;2) = \frac{e^{-2}(2)^4}{4!} = 0.09 \quad [4]$$

$$\Pr(1;0.5) = \frac{e^{-0.5}(0.5)^1}{1!} = 0.30 \quad [5]$$

The probability of the joint occurrence of these three outcomes is very unlikely. Its value is less than 0.004 as computed by the product of the probabilities of the individual independent outcomes. Because of the small chance of occurrence, this joint fire outcome poses little risk. However, many other combinations of fires in the three size classes will yield adverse outcomes. When aggregated, their total probability could pose a significant risk.

One way to computationally evaluate total risk is by enumerating, calculating, and aggregating probabilities for all joint fire occurrence outcomes that do not exceed some unacceptable level of burned hectares. Subtracting the resultant from 1.0 gives the desired risk estimate. For the three-class example, total risk is computed as:

$$1 - \sum_{k=0}^2 \sum_{j=0}^{8-4k} \sum_{i=0}^{200-100k-25j} \frac{e^{-0.5}(0.5)^k}{k!} \cdot \frac{e^{-2}(2)^j}{j!} \cdot \frac{e^{-7}(7)^i}{i!} = 0.134 \quad [6]$$

The upper limits on the summation signs are constructed from the threshold level of 2,000 hectares and fire sizes of 10, 250, and 1,000 hectares, respectively, for i , j , and k . The consequence of indexing through the summation signs is to enumerate and evaluate all combinations of fire events resulting in combined burned area less than or equal to the threshold. For example, when index k is 1 to signify one 1,000 hectare event in the combination, index j , signifying the number of 250 hectare events, can index 0 through 4 without the cumulative acres of events in these two fire classes exceeding 2,000 hectares. A similar process of indexing holds for i when combinations of fires in the k and j class do not exhaust the 2,000 hectare threshold.

Applying the Risk Assessment Techniques

Development of these quantitative methods suggested potential applications in wildfire risk assessment. The hypothetical data used in developing these methods are further considered in looking at the application of the risk assessment method. Attention focuses first on the creation of a risk profile for a resource management area. Afterwards, the method is used to look at trading off risk and cost when a management activity is proposed for mitigating potential fire behavior.

Creating a Risk Profile for a Project Area

Determining a minimum acceptable level of burned hectares consistent with meeting resource management objectives is often fraught with uncertainty. For example, in a watershed, depending on the intensities of wildfires and on other uncertain variables, the threshold separating acceptable and unacceptable outcomes may be unclear and might fall within a range of burned hectares. This uncertainty begs for more information on risk than a single probability estimate.

The solution to the problem is to conduct sensitivity analysis by calculating risk estimates over a range of burned area thresholds. This is illustrated for a 20,000 hectare watershed whose water quality is at risk to any combination of fire

events burning more than 2,000 hectares over a 3-year period. The watershed is estimated from historical data to have the following fire size class and frequency statistics for the 3-year period:

Size class	Mean fire size (hectares)	Mean fire frequency
1	10	12.00
2	250	3.00
3	1,000	0.75

From these statistics a risk profile for both periods is created for thresholds ranging from 1,000 to 3,000 hectares in steps of 500. Applying the computational methods developed earlier, the probability of burning a greater area than each hectare threshold gives the following risk profile:

Burned area threshold (hectares)	Probability of exceeding threshold
1,000	0.694
1,500	0.497
2,000	0.304
2,500	0.177
3,000	0.092

Probability estimates for the range of thresholds provide much more information than the single probability estimate for the 2,000 hectare threshold. The sensitivity analysis for the 3-year period clearly shows the risk of more serious outcomes decreasing rapidly. On the other hand, burning more than 1,000 hectares in 3 years is quite likely.

Trading Mitigation Cost against Risk Reduction

The risk of unfavorable wildfire outcomes can often be reduced in an area by resource management and protection activities. Fire size can be decreased by manipulating vegetation that fuels fire in ways that reduce fire behavior. Increased fire prevention efforts can reduce fire frequency. Additional initial attack fire suppression resources will contain fires more quickly and at smaller sizes. The benefit of these risk mitigation expenditures is not always fully measurable in dollars. Under these circumstances examining the improvement in the wildfire risk profile for an area may provide additional support for expenditures.

Trading mitigation cost for risk reduction is illustrated by expanding on the previous watershed example. A program for treating fire fuels in the watershed is proposed at annual cost of \$10,000 for purposes of mitigating fire behavior increasing fire suppression effectiveness. As a result most fires will be contained more quickly at smaller sizes. Although the average number of fires in each class is not expected to change over the 3-year period, the average size of fires in the three size classes is projected to decrease after treatment as follows:

Size class	Mean fire frequency	Mean fire size before	after
1	12.00	10	3
2	3.00	250	100
3	0.75	1,000	500

From the projected after treatment fire sizes, a new risk profile is calculated with the following results:

Burned area threshold (hectares)	Probability of exceeding threshold	
	before	after
1,000	0.694	0.240
1,500	0.497	0.066
2,000	0.304	0.014
2,500	0.177	0.002
3,000	0.092	0.000

Although this example is hypothetical, it does exemplify the kind of information to be expected from use of the risk assessment methods outlined in this paper. In this instance, by reducing fire size to about one-half, the fuels treatment program nearly eliminates the risk of adverse outcomes. A manager would have to decide whether this substantial risk reduction is worth the \$10,000 annual cost of the fuels treatment program.

This watershed example also illustrates another important point about risk assessment. If a change in average hectares burned is used as a proxy for a change in risk, as is often done, this can be misleading. The expected hectares burned in the 3-year period declined from 1,620 to just 701, whereas the probability of burning more than 2,000 hectares declined dramatically from 0.304 to 0.014.

Discussion

A critical aspect of every risk assessment is determining the probabilities of potential outcomes. When opportunities exist, using formal methods from probability theory can increase the quality of risk assessments.

This paper has provided one example of how the Poisson model and the mathematical methods of probability theory can be used to address a particular class of risk assessment problem in resource management. The quantitative technique described can improve on the probability estimates made by other means.

The technique does require input data on which to make probability calculations for the risk assessment, such as fire frequency and size used in the example. Most often these inputs must be estimated from sample data or acquired through expert judgment. To the extent estimates of the input data are precise, reliable, and unbiased, the resulting probability calculations will be of high quality.

On another note, reduction of the continuous distribution for fire size to a discrete distribution with few size classes may also create bias in the risk calculations. As threshold values approach the mean of a size class, probability estimates will tend to underestimate the true probabilities. This bias can be mitigated by choosing more size classes for the empirical distribution.

This paper did not address several issues and procedures for acquiring good data on fire frequencies and sizes upon which to make probability calculations. One that should be highlighted centers on the degree to which historic frequency and size data will represent conditions in the future. Ecosystems and fire suppression policies change over time. To the extent this occurs, the deeper the reach into the historic data pool and/or the greater the reach of the risk assessment into the future, the less reliable will be the probability calculations. A similar issue arises when data from a larger geographic area are used for estimating risk in a smaller area. These issues are beyond the scope of the current paper. Nevertheless, they warrant future research. Potential users of the risk assessment techniques described in this paper are cautioned to consider these matters.

Caution also should be exercised in the use of the methods described in this paper to assess the risk of adverse outcomes involving both magnitude and duration of a condition. If concern, for example, centers on assessing the risk of sustained habitat loss exceeding some duration, use of more sophisticated probability methods or stochastic simulation techniques will be required.

The methods outlined in this paper need not be confined to assessing burned acreage risk. Other random phenomena in resource management may follow Poisson processes with frequency and size attributes that make threshold risk assessment meaningful.

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Analysis of Area Burned by Wildfires Through the Partitioning of a Probability Model¹

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Abstract

An analysis of forest fires by using a partitioned probability distribution is presented. Area burned during a fire is fitted to a probability model. This model is partitioned into small, medium, and large fires. Conditional expected values are computed for each partition. Two cases are presented: the two-parameter Weibull and the Truncated Shifted Pareto probability models. The methodology allows a comparison of area burned and cost for small, medium, and large fires among different attack strategies. The partitioned functions may also be used as a basis to refocus fire management optimization with a multiple objective formulation.

Introduction

Fire management decisions are frequently made on the basis of many uncertain and highly variable factors, such as fire behavior, weather forecasts, fire effects, and performance of initial attack force. Although most of the modeling of these components have been deterministic, fire managers probably balance their judgments about the uncertain factors against their preferences for possible consequences or outcomes, deviating from the optimal solution provided by a decision-making model. All of these deviations from an optimum solution implicitly recognize the effect of large fires in deciding what level of effort or resources to allocate in fire management. Despite that forest fires are highly stochastic and complex events, most of the decision models that are used are based on techniques that use the expected value of the damage function, and a few others are deterministic models.

Fire management decisions obviously are influenced by the concern about the occurrence of large fires. Large fires with low probability of occurrence have a large impact in natural, social, and economic systems. However, most fires are extinguished in the initial stages and remain small. These smaller fires have a large probability of occurrence, but the resulting damage is practically negligible on an individual basis. Because of these probabilities, the expected value of a damage function misrepresents both extremes. Also, the use of expected value does not adequately represent the consequences associated with different fire management policies.

Traditional decision-making and budgeting in forest fire management have been based on the postulate that resources must be allocated in proportion to the resource value to be protected. However, it has been mentioned in several forums that the high costs of fire control are not justified when a strict economic analysis is made because the optimization criterion consists largely of costs (Gale 1977). Moreover, actions that are seen to reduce the risk of the occurrence of large wildfires justify high expenditures made on those large fires, as well as those made on smaller fires.

This paper presents a methodology to incorporate different damage levels in fire management decision-making by analytically incorporating large fires. The methodology partitions a probability model to describe area burned, to address different damage levels and their probability of occurrence. The assumption is

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that partitioning the probability distribution of fire damage will enable comparisons of the cost of different initial attack strategies for different damage levels.

The probability distribution of fire damage will be partitioned to segregate the small fires that have a large probability of occurrence but cause little damage, the large fires that cause extensive damage but have low probability of occurrence, and the intermediate events. By using this approach, more information about fire damage variability is accounted for in the decision process and large fires are analytically included.

Modeling the partition containing the large fires is emphasized because they are responsible for most of the damage caused to the forest. A great amount of resources are devoted to fighting or preventing large fires and on restoration. The few large fires, as opposed to the many small fires, are of interest to the public and have more influence on the policies of a fire organization.

Partition of a Probability Distribution

Show (1921) stated that large fires have been misrepresented in the current fire size classification systems because they have been pooled into a single fire class. He pointed out the need of subdividing the fire classes similarly to a geometric progression according to the fire size. In this paper, we propose that partitioning the distribution will reflect more accurately the fire occurrence distribution. The distribution function fitted to fire sizes is partitioned in three ranges. They represent three damage levels: the small fires with high probability of occurrence; the medium damage fires; and the large fires with a low probability of occurrence but high consequences.

For illustration purposes of the partition methodology, we used the two-parameter Weibull and the Truncated Shifted Pareto (TSP) distributions (Alvarado 1992). Those two distributions were fitted to the fire occurrence records from 1961 to 1988 for the Provincial Forest Service of Alberta, Canada; *table 1* includes the parameter estimates for those two distributions. The data was also separated by resources used in the initial attack: fires in which only man power was reported, those in which air attack was used, and those fires in which man and other equipment different than aircrafts were used.

The number of partitions into which the probability axis is divided depends on the nature of the problem and concerns of the decision-makers. In cases where risk is involved, three partitions are usually made: one is the range for high frequency events with low damage; one for intermediate events; and a third one consisting of the events that represent large losses with low probability of occurrence.

Table 1- Parameter estimates for the two-parameter Weibull and the Truncated Shifted Pareto distributions.

Initial attack strategy		Parameter estimates			
		Two-parameter Weibull distribution			
	c	ase ¹	a	ase ¹	
All fires	0.3263	0.0014	1.718	0.0382	
Manpower only	0.3442	0.0193	1.3028	0.0364	
Air attack	0.3044	0.0024	2.4165	0.11	
Ground attack	0.3344	0.0036	2.4496	0.1349	
		Truncated Shifted Pareto distribution			
	a	ase	b	ase	
All fires	0.0605	0.0012	2.1585	0.0197	
Manpower only	0.0553	0.0013	2.0033	0.0243	
Air attack	0.0727	0.0029	2.2821	0.0404	
Ground attack	0.0769	0.0041	2.3241	0.0551	

¹ Asymptotic standard error of the estimate.

There is no consensus in the literature on the level at which events should be considered as extremes. In some instances the cut-off is made for practical reasons on the probability axis. These are referred to as the "events that exceed a quantile." Examples are sea wave extremes that exceed the level 1:10,000 (Dekkers and Haan 1987) or those with large return periods, e.g., rain depths with a return period of more than 100 years (Foufoula-Georgiou 1989). Large forest fires are usually referred to in terms of area burned. The variance may also be used if the normal distribution is used as a risk function, e.g., one or two times the variance. Another approach is to use past experience regarding damage levels, e.g. fire size classes, emergency state declarations, or others.

The partitions mapped on the probability axis can represent three damage levels (fig. 1). The 1 to $1-\alpha_i$ range include the events with large probability of occurrence but cause the lowest damage (0 to β_{ij} interval on the damage axis). The events bounded by α_i and α_{i+1} are those events causing an intermediate damage. Extreme value theory and risk management focus on events known as *low probability/high consequence* events. These are the events in the lower partition of the probability axis that cause the most damage (fig. 1).

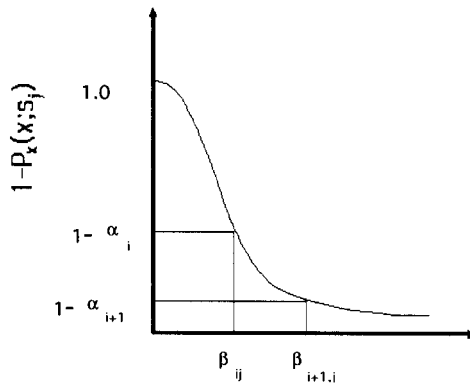


Figure 1

Mapping of the partition of the probability axis onto the damage axis (Asbeck and Haines 1984).

The partitions used in this study are based on the fire size classes defined by Canada's Province of Alberta (Alberta Forest Service 1985). The first partition includes the fire size classes A and B, which includes the fires that burned from 0.1 to 4.0 hectares. For the second and third partitions we presented two cases. For the second partition, the upper limit depends on the lower limit of the large fire level. It consists either of those in size classes C and D, i.e., from 4 to 200 hectares; or it includes C and D and part of E classes, with the lower limit larger than 4 hectares and the upper limit set to exclude the upper 1 percent of the fires. The third partition encompasses the large fires. Two cases of large fires are studied: fires in the size class E, i.e., larger than 200 hectares, and fires in the upper one percentile of the observed distribution.

Once the partition values are defined either in terms of probability or damage, they are mapped onto both the probability and damage axis. Asbeck and Haines (1984) and Karlsson and Haines (1988b) consider that the problem is to find a β_{ij} for each partition point α_i for $i=1, \dots, n$, and values of s_j for $j=1, \dots, q$, such that $P(\beta_{ij}; s_j) = \alpha_i$. Then, the existence of a unique inverse $P_x^{-1}(x; s_j)$ is guaranteed from the following standard probability assumptions: the $p_x(x; s)$ is nonnegative and:

$$\int_{-\infty}^{\infty} p_x(x; s) dx = 1 \quad [1]$$

with the probability of $(a < X < b)$ given by:

$$P(a < X < b) = \int_a^b p_x(x; s) dx \quad [2]$$

The probability and damage axes are partitioned into a set of n ranges, three

in this paper. The partition points on the probability axis are denoted by α_i . For each partition point and variable s_j , the three initial attack strategies as defined in the study, there exists a unique damage or loss β_{ij} such that:

$$P_X(\beta_{ij}; s_j) = \alpha_i \quad [3]$$

Because the inverse $P_X^{-1}(x; s_j)$ is assumed to exist, thence:

$$\beta_{ij} = P_X^{-1}(\alpha_i; s_j) \quad [4]$$

If the interest is to represent the large fires without being restricted to a parent distribution, in addition to partitioning of a distribution function, other methodologies can be used. One of them is to select an upper threshold so high in the parent distribution such that the exceeding observations converge to one of the extreme value models. For the case of wildfires, the fire size observations are highly concentrated on the first fire classes. Thus, distribution of fires in the upper size class, or those in an upper percentile may converge to an extreme value model (Alvarado 1992). This model is the limiting convergence of the right tail of the parent probability model, and will include only the large fires.

Another approach is to create the proposed functions with a censoring approach. The idea is that the right tail exists, but it is beyond the local fire fighting capabilities. The reasoning for this approach assumes that the fire organization's efforts did not maintain the size of these fires within the domain of the censored distribution. Regardless of the approach, the fire size distribution can be included in an optimization problem as a set of functions, both the unrestricted distribution and the restricted partitions of it.

Conditional Expected Values

The computation of the conditional expected values is a question of defining the probabilities that the random variable X falls within each of the selected partitions (Houghton 1988, Karlsson and Haimes 1988a). The β_{ij} , specified in equation 4, are used for the definition of the conditional expectations. They are formally expressed by:

$$f_i(s_j) = E\{x \mid P_X(x; s), x \in [\beta_{ij}, \beta_{i+1,j}]\} \quad [5]$$

Represented in an integral form, the conditional mean is expressed by:

$$f_i(s_j) = \frac{\int_{\beta_{ij}}^{\beta_{i+1,j}} x p_X(x; s_j) dx}{\int_{\beta_{ij}}^{\beta_{i+1,j}} p_X(x; s_j) dx}, i = 1, K, q \quad [6]$$

Let θ_i , denote the denominator of equation 6, then from using the assumption from equation 2:

$$\theta_i = \int_{\beta_{ij}}^{\beta_{i+1,j}} p_X(x; s) dx = P_X(\beta_{i+1,j}; s) - P_X(\beta_{ij}; s) \quad [7]$$

Equation 7 can be stated in terms of the probability partition points (*fig. 1*) as:

$$\theta_i = \alpha_{i+1} - \alpha_i \quad [8]$$

Substitution of the equation 8 into 6 gives the following general equation to compute the conditional expected values:

$$f_i(s_j) = \frac{1}{\alpha_{i+1} - \alpha_i} \int_{\beta_{ij}}^{\beta_{i+1,j}} x p_X(x; s_j) dx \quad [9]$$

The conditional expectation of the fire size distribution, given that the fire is in that partition, is in some sense an incomplete first moment (Raiffa and Schlaifer 1961) or an expected mean for a certain range (Houghton 1988). Notice in equation 9 that if the partition points occur at 1 and 0, i.e., the integration is over the entire distribution range, then, the equation becomes the unconditional expected value.

In the case of the first partition, the conditional expected value depends only on the upper partition point $\hat{\alpha}_i$ that represents the cumulative probability that determines the upper bound of the low damage range. Equivalently, the partition point α_i on the probability axis corresponds to the partition points β_{ij} on the damage axis (fig. 1). The conditional expected value of the second partition, which defines the intermediate damage, depends on two partition points, α_i and α_{i+1} . The third partition corresponds to α_{i+1} to 1.

An analytical solution to equation 9 generally does not exist. Karlsson and Haimes (1988a, 1988b) developed a methodology for solving the equation for certain distributions and parameter values. They found it easy to solve for the exponential case. They derive near-closed-form expressions for the normal and lognormal distributions. As for the Weibull, a closed form may not exist, depending on the values of the shape parameter.

Houghton (1988) presents a closed form solution for the TSP distribution. Although he derives it by partitioning on the x -axis and calls it *mean over a range*, the result is a closed form of the integral 9. Houghton derives the formula using the complementary cumulative distribution $G(x)=1-F(x)$. In the formula over the range, $x_d=\beta_{ij}$ to $x_e=\beta_{i+1,j}$ are equivalent to the partitions on the probability axis $G_e=\alpha_{ij}$ to $G_d=\alpha_{i+1,j}$. The mean over a range is defined by:

$$\bar{x}_{d,e} = \frac{1}{G_d - G_e} \int_{x_d}^{x_e} x f(x) dx \quad [10]$$

Because the inverse (equation 4) is guaranteed to exist from the probability assumptions, let $y=G(x)$, $x=G^{-1}(y)$ and $dy=f(x)dx$, then:

$$\bar{x}_{d,e} = \frac{1}{G_d - G_e} \int_{G_e}^{G_d} G^{-1}(y) dy \quad [11]$$

$$\bar{x}_{d,e} = \frac{1}{G_d - G_e} \int_{G_e}^{G_d} [a\{[T^u(1-T^u)G]^{-b} - 1\} + x_c] dG \quad [12]$$

which gives the equation presented by Houghton (1988) to compute the expected value over a range:

$$\bar{x}_{\beta_{ij}, \beta_{i+1,j}} = x_c - a + \frac{a\{[T^u + (1-T^u)\alpha_{i+1,j}]^{1-b} - [T^u + (1-T^u)\alpha_{ij}]^{1-b}\}}{(1-T^u)(1-b)(\alpha_{i+1,j} - \alpha_{ij})} \quad [13]$$

Equation 13 can be expressed in terms of the α 's and β 's partition points as:

$$\bar{x}_{d,e} = x_c - a + \frac{a\{[T^u + (1-T^u)G_d]^{1-b} - [T^u + (1-T^u)G_e]^{1-b}\}}{(1-T^u)(1-b)(G_d - G_e)} \quad [14]$$

For the Weibull model, Karlsson and Haimes (1988a) found that a closed form exists only if the inverse of the shape parameter, c , is a positive integer. If it is the case, the following equation applies:

$$f_i = \frac{a}{\alpha_{i+1} - \alpha_i} \left\{ (1 - \alpha_i) \left[\left(1 - \frac{1}{1 - \alpha_i} \right)^{1/c} + \sum_{k=1}^{1/c} \left[\left(1 - \frac{1}{1 - \alpha_i} \right)^{k-1} \prod_{j=k}^{1/c} j \right] \right] - (1 - \alpha_{i+1}) \left[\left(1 - \frac{1}{1 - \alpha_{i+1}} \right)^{1/c} + \sum_{k=1}^{1/c} \left[\left(1 - \frac{1}{1 - \alpha_{i+1}} \right)^{k-1} \prod_{j=k}^{1/c} j \right] \right] \right\}$$

For the case of $1/c$ not integer, which is the case most of the time, a numerical integration technique must be used to solve equation 9. The expression $1/c$ is an integer only in cases where the Weibull's c parameter is equal to or less than one. It must be recalled that the desirable properties of the Weibull distribution do not hold for shape parameter values less than one.

Numerical integration methods are used to evaluate definite integrals that can not be evaluated analytically. Basically, the numerical integration methods are rules to integrate a function over a small number of intervals by subdividing the interval $[a,b]$ into n equal parts of length $h=(a-b)/n$ (Press and others 1986).

Table 2-Conditional means for the first two partitions of the two-parameter Weibull and the Truncated Shifted Pareto distributions.

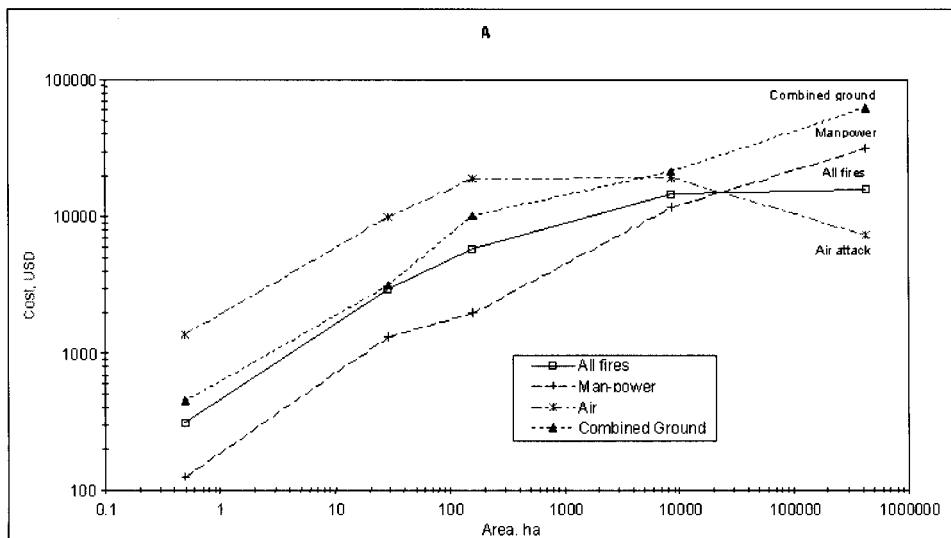
Fire classes/ size range, ha	Partition points		Conditional means ¹	
	α_i	α_{i+1}	Weibull ²	TSP ³
All Fires- sample mean: 179.36				
Entire distribution ⁴	1.0000	0	11.1868	156.14000
A-13/0-4.0	1.0000	0.1453	0.5395	0.49590
C-D / 4.0-200	0.1453	0.0223	58.3031	29.18050
C-99 pct/4.0-874	0.1453	.0100	74.5375	68.26610
D+/200+	0.0223	0		3096.58000
>99pct/>874	0.0100	0		6701.10000
Manpower only- sample mean: 72.65				
Entire distribution ⁴	1.0000	0	6.9489	56.41000
A-13/0-4.0	1.0000	0.1299	0.5540	0.41950
C-D / 4.0-200	0.1299	0.0162	46.3264	24.87200
C-99 pct/4.0-441	0.1299	0.0100	50.6339	38.95090
D+/200+	0.0162	0		1639.35000
>99pct/>441	0.0100	0		2564.08000
Air attack: sample mean: 385.60				
Entire distribution ⁴	1.0000	0	20.9786	398.44000
A-15/0-4.0	1.0000	0.1588	0.5112	0.61907
C-D / 4.0-200	0.1588	0.0332	75.9436	29.51370
C-99 pct/4.0-3185	0.1588	0.0100	133.8069	119.87100
D+/200+	0.0332	0		4957.43000
>99pct/>3185	0.0100	0		16166.60000
Ground attack: sample mean: 206.74				
Entire distribution ⁴	1.0000	0	14.5222	546.31000
A-13/0-4.0	1.0000	0.1784	0.5699	0.59165
C-D / 4.0-200	0.1784	0.0254	53.5775	43.0875
C-99 pct/4.0-757	0.1784	0.0100	67.4529	132.18900
D+/200+	0.0223	0		8645.00000
>99 pct/>757	0.0100	0		21698.70000

¹ Parameters estimated with the maximum likelihood method.

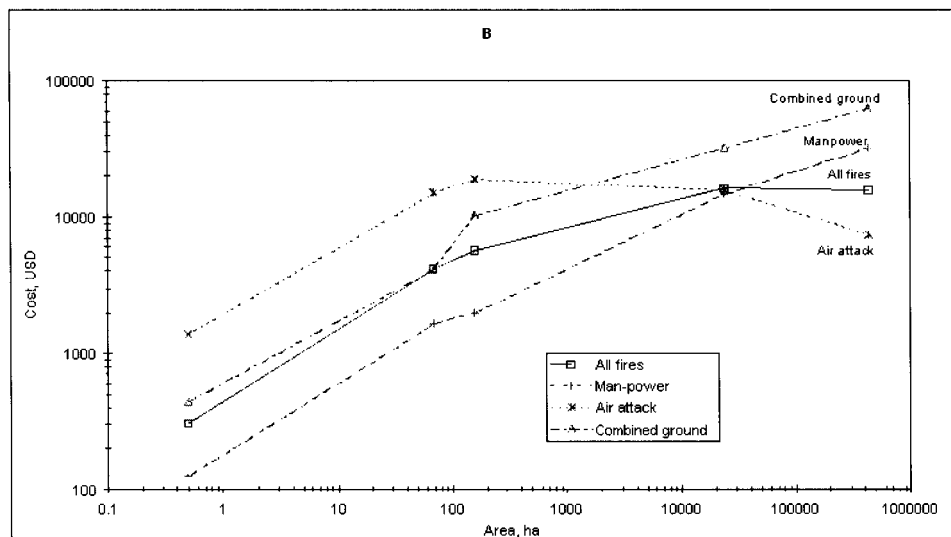
² Means approximated with the Newton-Cotes 8 panel rule.

³ Means computed from the exact closed form equation.

⁴ Unconditional mean.

**Figure 2**

Relation between cost and expected area burned of different partitions by initial attack strategy. A) Lower threshold for the upper partition set at 200 hectares. B) Lower threshold for the upper partition set at 99 percent of the distribution.



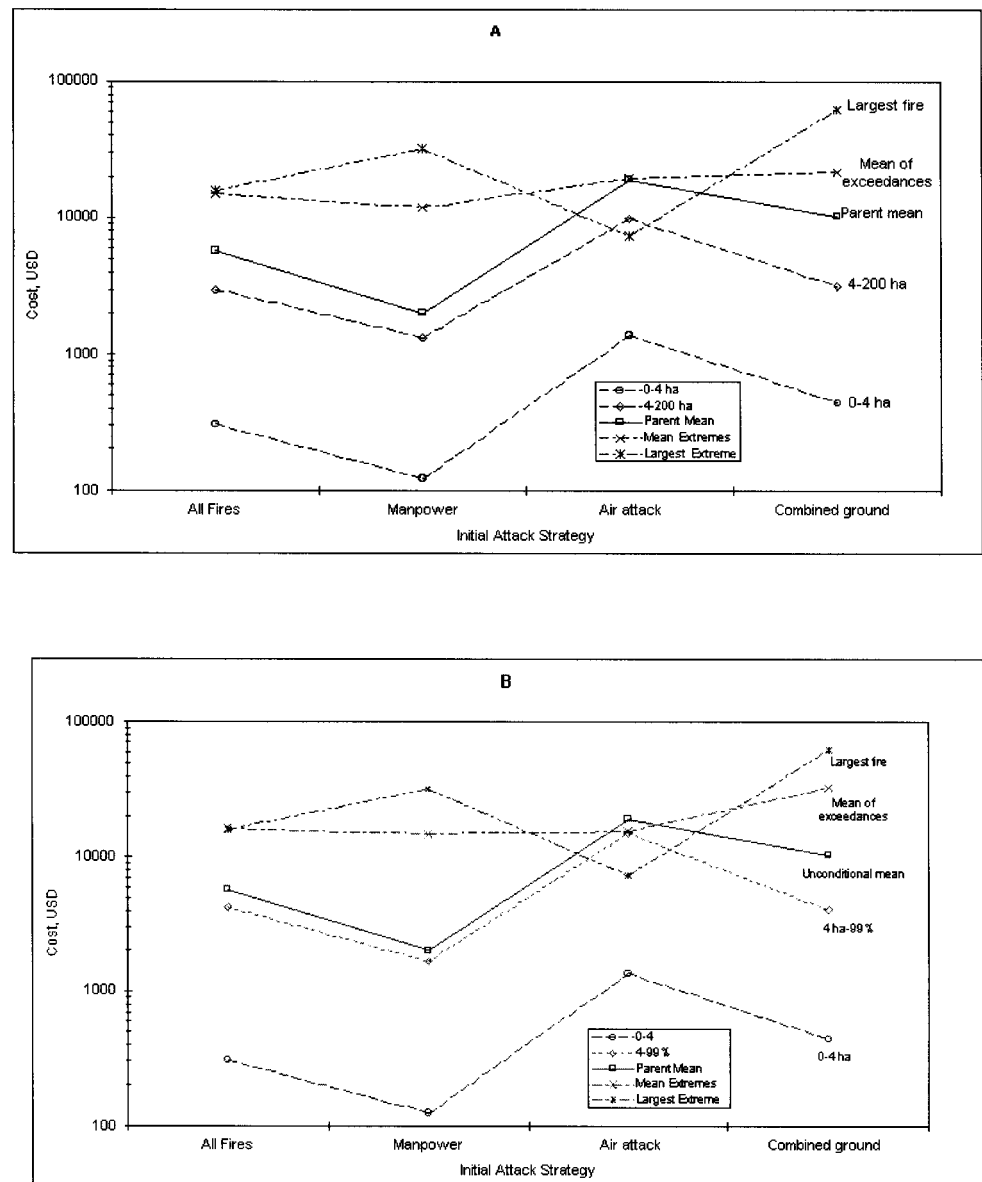
There are a variety of methods for evaluation of integrals, among them Simpson's rule, Newton-Cotes formulas, Romberg's integration, and Gaussian quadratures.

Numerical integration algorithms are commonly available in public domain software and in most of the commercial mathematical software. The method used in the study was an adaptive recursive Newton-Cotes 8 panel rule, implemented in most mathematical software. The advantage of using this rule over Simpson's, which is the most commonly used, is that it avoids numerical overflow when evaluating functions with soft singularities. That is the case of the Weibull distribution that becomes unbounded at the origin if the shape parameter, c , gets close to zero. In that case, the integration of the first partition is unbounded if integrated from zero. The problem was avoided in this study by shifting the lower limit slightly away from zero (e.g., to 0.05).

In cases where the Weibull's shape parameter is close to zero, it may be preferable to use one of the open or semi-open type numerical integration rules (Abramowitz and Stegun 1972) for which several algorithms are also available (Press and others 1986). The conditional expected values were computed for the first two partitions of the two-parameter Weibull and the TSP distribution (table 2). For the third partition, only the TSP was calculated (Alvarado 1992, Alvarado and others 1998).

Figure 3

Expected cost by initial attack strategy of the expected area burned for several partitions of the fire size distribution. A.) Lower threshold for the upper partition set at 200 hectares. B.) Lower threshold for the upper partition set at 99 percent of the distribution.



The conditional means computed for the first partition of the TSP differ only slightly from that of the Weibull's. However, the discrepancies are larger for the partition included in the fire classes C and D. The same situation occurs for the second partition when the upper limit is 99 percent of the distribution. That occurs because as it was seen in a preliminary analysis from probability plots, the TSP better fits the upper part of the distribution. The opposite situation was observed for the Weibull's plots, which presents a concave pattern over all the prediction range.

The conditional means for the Weibull for the initial attack strategies are larger than the global or unconditional means. That does not seem logical because if larger fires are included, then the distribution mean should increase; but, this did not happen in this study because of the short-tailed attribute of the Weibull distribution. A monotonic increasing trend is seen in both the conditional and unconditional expected means of the TSP distribution. Again, that is because of TSP being a long-tailed distribution. The better fit over the entire distribution and better representation of the conditional means over the larger fire sizes supports the selection of the TSP over the Weibull to represent the entire fire size distribution.

Application of Conditional Means to Fire Cost Analysis

We present the relation between the expected cost for initial attack strategies and the expected area burned for the entire probability distribution. We present the conditional expected values and the expected area burned for the fires exceeding a threshold. The cost function was developed by Alvarado (1992) on the basis of previous work by González-Cabán and others 1987.

The costs for the unconditional expected area burned were calculated as well as the two lower partitions of the fire size distribution, and the expected value of fires exceeding a threshold (*figs. 2, 3*). It can be seen from these plots that the expected cost for small and medium fires is greater when using air attack and lower when using manpower only. The cost for the expected area of the all-fire data set resembles the ground attack strategy. Obviously, the cost of the expected area does not represent adequately the cost of manpower nor air attack. It is obvious that the global expected cost over predicts the small fires and completely misrepresents the cost of large fires.

When fires get larger, the parallel relation existing for the cost of small and medium fires does not hold. It can be observed that for large fires cost patterns are different from those observed for small fires. For large fires, it becomes more expensive to attack with either manpower only or ground equipment than to use air attack. That relation is reasonable because the amount of manpower and ground equipment units allocated to a large fire conflagration need to be excessively large to provide efficient fire fighting. The cost of maintaining such a large force also grows exponentially.

In contrast, the number of air attack units is more limited than the other fire fighting resources; therefore, the air cost does not increase as fast. In fact, the cost may decrease as fires grow larger (Gale 1977). There may be several reasons for this. The weather conditions that generated the large fire situation may likely have changed; subsequently, the fire may behave less threatening than at the active-growing phase. Usually, there is also an expenditure ceiling, which means that economic resources are not infinite. Additionally, the efficiency of ground attack crews and equipment may greatly improve when there is air support.

The difference of setting the threshold for the third partition at 200 hectares or 99 percent of the distribution is also observed in the cost of the expected area burned. When the third partition includes only the upper one percentile of the distribution, the expected costs of large fires of the manpower and air strategies, as well as the pooled all-fire data, are very similar. It seems that more partitions on the probability distributions would allow an equilibrium point between the cost of the different strategies, where there is cost indifference for pairs of initial attack strategy.

One immediate result of having several functions that describe different damage levels and costs for different initial attack strategies is that the optimization can be solved through multiple objective techniques (Chankong and Haimes 1983a, Karlsson and Haimes 1988b, Keeney and Raiffa 1976, Waller and Covello 1984).

The important role of large forest fires in fire management decision-making has never been neglected by fire managers. However, to date they have always been excluded from most of the analytical models. The solution to this problem has always been to resort to present empirical and subjective answers.

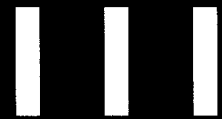
In conclusion, we propose to find a distribution function that better approximates the distribution of fire sizes. This distribution is then partitioned into ranges that represent different fire damage levels. The purpose of using this distribution is to represent the small, medium-sized fires. The partition that includes the large fires is approached from the perspective that they exceed a specified threshold. These thresholds may be given in actual area burned or may include fires in an upper percentile.

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Session



Approaches to Fire Planning in Different Agencies

*Chairs: Wayne Mitchell, G. Thomas Zimmerman,
Armando González-Cabán*

The National Fire Management Analysis System (NFMAS) Past 2000: A New Horizon¹

Stewart Lundgren²

Abstract

Wildland fire suppression policy in the USDA Forest Service has evolved over the years from forceful attempts to control all wildland fires at the smallest possible size to consideration of other land management and economic factors during suppression decision making. In 1978, working under congressional direction, the Forest Service started using and developing computer-based models to represent the benefits and costs of budget requests. Over time, the National Fire Management Analysis System (NFMAS) was implemented as the primary fire planning system in several Federal and State agencies. The NFMAS is a tool used by managers to evaluate alternative fire management programs against such things as land management objectives, program budget level, and dispatch strategies. In order to meet future information requirements, the NFMAS will need reengineering and enhancement in several areas. Scientists, software engineers, agency personnel, and others need to work together so the next generation NFMAS meets the needs of the user community, managers, and agency administrators.

The National Fire Management Analysis System (NFMAS) provides the basis for planning and budgeting of the USDA Forest Service Fire and Aviation Management program. By using the NFMAS, long range budget requests are prepared at the National Forest, Regional, and National organizational levels. Current year allocation is based upon those requests and available appropriation. The NFMAS is a fundamental tool to show Congress and the Office of Management and Budget (OMB) the value of financing the Fire and Aviation Management program. In recent years, several refinements to the original NFMAS have been developed. They improve the ability of the model to reflect and project Fire and Aviation Management program needs and outcomes.

This paper provides a brief history of the NFMAS, outlines the current status of the NFMAS, and discusses future enhancements that might be incorporated into the fire planning system.

A Brief History of Forest Service Fire Policy and Fire Planning Systems

Since the early years of this century, the USDA Forest Service has protected the lands it manages from undue damage by wildfire. Over the decades, a variety of criteria and philosophies has been used to identify the most appropriate kind and use of wildfire suppression resources (personnel and equipment).

One of the earliest measures of efficiency produced the "10 a.m. Fire Control Policy." This policy called for "fast, energetic, and thorough suppression of all fires in all locations, during possibly dangerous fire weather.... Failing in this effort, the attack each succeeding day will be planned and executed with the aim, without reservation, of obtaining control before 10 o'clock of the next morning" (Silcox 1935, p. 1).

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This policy was grounded in the philosophy that all fires represented a threat of unacceptable damage and that it was more cost-effective to aggressively suppress wildfires at a small size than to allow them to get larger and then try to extinguish them.

In 1971 the Forest Service adamantly reaffirmed the 10 a.m. Fire Control Policy but recognized that conditions and situations varied across the country. There was also a prediction of a time "when a more flexible approach should be considered. It is anticipated that fire planning, fully supported by dependable data and knowledge, will permit suppression goals based on local judgements and decisions" (USDA Forest Service 1971, p. 1).

The next year, in the process known as "1972 fire planning," the agency specified that fire planning must provide a level of protection necessary for successful management of natural resources and to improve and protect air, water, soil, and visual quality. It stated that this must be done at the least cost commensurate with values protected. Preparedness forces were to be developed and financed at a level sufficient to manage fire problems encountered 90 to 97 percent of the time, as measured by the National Fire Danger Rating System (NFDRS) burning index. This signaled a substantial departure from the single minded mandate of "thorough suppression of all fires in all locations."

By 1975, the escalating cost of Forest Service fire management programs, without apparent commensurate reductions in suppression costs and resource damage, had caught the attention of the OMB. The next year, the Chief of the Forest Service requested that fire planning methods be reviewed, with special attention given to preparedness effectiveness. The ensuing study concluded that "the fire planning procedures appeared to be basically sound and rational" (USDA Forest Service 1976). It recommended:

- Setting fire control objectives based on output targets from the Resource Planning Act (RPA) and land and resource land management plans.
- Adjusting initial attack organizations based on planned fire prevention efforts.
- Projecting acres burned based on local fuels, weather and topography, and calibrating it according to local experience.
- Utilizing mathematical regression analysis to evaluate protection costs and results (Ellis 1969).
- Evaluating the Fire Operational Characteristics Using Simulation (FOCUS) model for expressing the effectiveness of preparedness expenditures, including the potential damages and benefits from wildfire, and the organization that can meet objectives at the least cost.
- Indicating the most cost effective, "mix of presuppression activities."
- Conducting economic efficiency analysis at a Regional level aggregating upward to produce a national evaluation.

In 1978 Congress directed the Forest Service to conduct a formal cost-benefit analysis to support the fiscal year 1980 budget request. The next year, a computerized tool called FOCUS was used to analyze several years of historic fires on six National Forests to provide budget planning guidance. FOCUS provided information on wildfire suppression efficiency but could not be used for development of a national fire management budget. However, on the strength of that analysis, Congress increased the 1980 budget for fire management, but directed that any further increases would be withheld pending findings of a more comprehensive cost-benefit study.

A more comprehensive study was conducted in 1980 by using a different set of computerized tools to analyze 10-year fire distributions on 41 National Forests, representing different vegetation, resources, fire behavior conditions, and fire budget levels (USDA Forest Service 1980a, USDA Forest Service 1980b).

Preparedness budget needs for the entire National Forest System were extrapolated from these sample data and used to generate the 1981 budget request. Congress expressed support for the analysis results and urged full implementation of the analysis process the next year. The Chief mandated the use of economic efficiency as the principle measure for appropriate budget levels and directed the Washington Office to use this prototype analysis for national budget preparation in the future.

The 1980 Fire Management Budget Analysis compared alternative fire program mixes, then identified the preferred mix as that which satisfied land management objectives at the lowest cost plus net value change in natural resources as the result of wildfire. Although useful in describing fiscal efficiency at the national level, important cost centers (facilities, airtankers, smokejumpers, Regional offices, and the National Office) were not analyzed. These cost centers were added in after the analysis to derive the national budget level. Neither the database, the evaluation process, nor the outputs were sufficiently accurate or precise for direct comparison between Regions or individual National Forests. This was primarily due to inadequacies in the database rather than deficiencies in the analytical process (USDA Forest Service 1980b).

The 1980 analysis recognized that natural resource value changes did not drive program efficiency determination. The change in natural resource value represented smaller amounts than either preparedness or suppression costs. The analysis showed that net value change was primarily the result of losses to the timber resource, followed distantly by destruction of improvements. The greatest benefits were to commercial livestock forage, wildlife habitat, and usable water yield. Although the analysis did not specifically evaluate fuel treatment investments, it did conclude that in certain site specific and limited vegetation complexes, larger fuel treatment programs may be effective in reducing wildfire suppression costs. The analysis concluded that the greatest opportunity for cost reduction exists where high fire occurrence rates and high resource values coincide.

Despite the incomplete nature of the 1980 analysis, it was sufficient to demonstrate a fully reliable process for describing economically efficient fire management program benefits. This was the beginning of the current NFMAS.

The National Fire Management Analysis System (NFMAS)

In 1925, W. N. Sparhawk laid the early foundation for the NFMAS. He searched unsuccessfully for a scientific method and formula to determine fire protection budget levels for the National Forests. Through his work, he established the basic efficiency principles and cost plus net value change graph that are familiar to fire planners today. His study sought efficiency based on least protection costs plus losses incurred by wildfire. Consequently, it ignored what was known about the beneficial effects of some wildfires. His model tended to overestimate damages (Gorte and Gorte 1979, Teeter 1983).

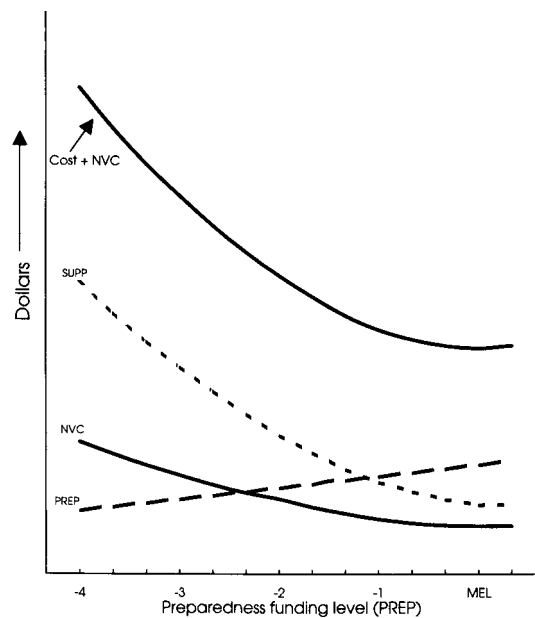
The NFMAS refines Sparhawk's approach and estimates the most cost efficient fire management program mix, as indicated by the lowest sum of costs plus net value change, which meets resource management objectives and provides the necessary level of protection to life, property, and resources. Costs are both preparedness and suppression. Net value change considers the benefits and damages of wildfire on both natural resources (market and non-market values) and improvements. The NFMAS rejects former physical indicators or decision criteria, such as acres burned and the 10 a.m. control policy.

Initial Attack Assessment and the NFMAS Model

There are numerous components to the NFMAS model. In general, it is based on historic fire occurrence, fire behavior, alternative initial attack organizations, and

Figure 1

National fire management and analysis system (NFMAS) and cost plus net value change (C+NVC) chart: relationship between preparedness (PREP), suppression operations (SUPP), and net value change (NVC).



results of simulated fires that are captured or escape initial attack. The Interagency Initial Attack Assessment (IIAA) model within the NFMAS tests alternative initial attack organizations and dispatch strategies against wildfire conditions found on the planning unit (typically a National Forest).

The IIAA provides a simulation of wildland fire initial attack response and applies a measure of economic efficiency to each response. The key concept in the fire planning process is that there are numerous alternatives to organizing, deploying, and using initial attack forces, but only one "most efficient level" (MEL). MEL describes the one mix of initial attack organization (engine crews, hand crews, smokejumpers, helicopters, and retardant use) and the one dispatch philosophy (how and when particular firefighting resources are used during initial attack) that minimizes the predicted aggregate cost of providing the initial attack organization (preparedness) plus the cost of wildland fire suppression plus the value of natural resources due to wildland fire. This sum is more commonly referred to as "cost plus net value change" (C+NVC). Fire planners systematically define alternative initial attack organizations and dispatch strategies and test them in the IIAA to find the most economically efficient staffing and dispatch philosophy.

A guiding principle in fire planning and the C+NVC concept is that there is a point at which additional expenditures in preparedness do not return a net savings in suppression expenditures plus natural resource loss (*fig. 1*). C+NVC is composed of three elements: The cost of supplying an initial attack organization (preparedness - PREP, *fig. 1*); the cost of wildland fire suppression (suppression - SUPP, *fig. 1*); and the value of natural resources lost due to wildland fire (NVC - NVC, *fig. 1*). The MEL occurs where the aggregate of these cost elements is minimized.

If a unit finances a small initial attack organization (point -4, *fig. 1*), some number of fires will escape initial attack. These escaped fires will grow in size, damage natural resources, and have high suppression costs. As the unit adds firefighters and the preparedness budget grows (points -3, -2, and -1, *fig. 1*), the number of escaped fires should decrease. This will lead to fewer acres burned, a lesser amount of natural resource damage, and reduced suppression cost. The relationship of reductions in natural resource damage and suppression costs in respect to increases in preparedness expenditures continues until a point where the efficiency of the initial attack organization is maximized (point MEL, *fig. 1*). Adding any more to the preparedness budget will not return an equal savings in resource loss averted plus suppression costs. Thus, at some point, no matter how much additional is spent on preparedness, some fires are going to escape, grow

large, and have a large suppression cost. It makes no economic sense to plan for these occurrences and maintain large preparedness organizations in the hope that every fire can be caught during initial attack.

The IIAA does a credible job of representing the results of alternative initial attack organizations. As a "marginal analysis" tool it estimates the magnitude of changes in outputs, specifically costs and losses, resulting from a known change in the inputs (Gorte and Gorte 1979, Teeter 1983).

The model is currently plagued by these weaknesses:

- Defining adequate overhead support cost information.
- Incorporating subjective non-market resource values (Hurd 1987).
- Recognizing the costs of social and political pressure.
- Adapting to small or low fire occurrence databases.
- Evaluation of prevention and fuel treatment programs.
- Evaluating fire season severity from one year to the next (Chase 1991).

Efforts are underway to address these deficiencies.

The Future of the NFMAS

Numerous enhancements and new functionality have been identified that will increase the effectiveness of the NFMAS as a planning tool and prepare the way for a replacement system.

Initial Attack Assessment

Input and output units are limited to U.S. units. A metric version would help planners in other countries.

The user guide and system technical documentation are written in English. It may be beneficial to translate these documents into other languages.

Fire planners now must enter vast amounts of derived information in order to set up an analysis. It is desirable to produce a "minimum necessary information" module that will allow planners, without large fire and weather occurrence and historic fire fighting organization databases to run the IIAA.

There are many opportunities to increase the amount of automation that now occurs in the IIAA. Assuming the fears of overautomating the system are overcome, these procedures will reduce the amount of planning time and increase the amount of analysis time available to fire planners. The program can be restructured to allow the machinery to run many more simulations than the fire planner. Some cost data can be empirically derived. Model development can take place that will allow for "extended attack" simulation (simulations that look at 1-2 days rather than hours) and long range simulation (1 week or more).

Advanced simulation tools need to be incorporated into initial attack and other fire planning exercises (large fire suppression decisions, land management planning, fuel treatment, and wildfire suppression training). Numeric data must be able to be transformed into visual information (motion, color, and graphic) for ease of discussion, location of "critical" areas, predictions of future events, and depictions of events.

The current model is limited to simulating one fire at a time. In the western United States, lightning storms can cause numerous fires in a short amount of time. The IIAA can be modified to include queueing theory or service/ supply modeling techniques to indicate how organizations should respond to multiple fire events.

Better and more defensible information is needed regarding the valuation of non-market forest resources and the effect wildfire has on them. Currently, the IIAA does not do a good job of handling non-market wildfire effects. Better damage functions, defensible values for non-market resources, and critical thresholds for resource damage need definition in the present or future system.

Weather Analysis

Seasonal or yearly fire severity analysis needs to be more fully developed. Climatological predictions of fire severity may help planners shift preparedness forces to those areas likely to have increases in normal fire occurrence.

Climatological predictions can be applied to geographic information systems (GIS) based fire spread models to aid managers with suppression alternatives and subsequent suppression decisions. Longer range climatological information prediction systems will be an important part of future fire planning and simulation.

Fuel Treatment

Reducing the amount of dead woody material in forests should reduce the rate of spread and intensity of a wildland fire burning in that forest. This should lead to reductions in preparedness expenditures as any fire burning in treated forests is more easily controlled. A problem facing fire planners at this time is how much fuel treatment is economically defensible. Development work on an economic model that describes the trade-offs of fuel treatment expenditures versus preparedness expenditures is desirable. Work has started on numerous elements of this problem. Eventually, many of the projects will yield products that will be combined into one system that will help managers define the costs, benefits, trade offs, and value of fuel treatment.

Work is needed in the area of how various treatments (prescribed burning, handpiling, machinepiling) affect fuel models. Cost and effectiveness information of each treatment type will be needed to feed the fuel treatment model.

Work has been completed on a first generation system (FORBS). Future work will build upon this base and introduce more of the complexities surrounding fuel treatment decisions.

Wildland Fire Prevention Programs

If prevention programs are successful, the number of human caused fires should decline. This success should manifest itself in reductions in suppression expenditures and natural resource loss. A model (PWA2) has been developed to test this theory. Peer reviews and enhancement of this model will be made in the future.

Geographic Information Systems (GIS)

Forest vegetation growth and decay has a profound affect on predicted fire behavior and selection of areas for fuel treatment. GIS-based, graphic data displays of data allow better and more accurate communication between managers. A model that can predict future forest vegetation types across a GIS landscape will help managers decide where to place fuel treatment and land management emphasis.

GIS based systems will allow better simulations of initial attack, will help with Wildland Fire Situation Analysis projections of escaped fires, and will assist managers with land management planning decisions. Fire planning will eventually involve more robust simulation tools that will allow long range predictions of wildfire events, land management planning decisions, and fuel treatment decisions.

Visual displays of quantitative information will be an important part of future systems development. Visual simulations of real time and predicted events will aid decision makers and simplify presentations of decision alternatives.

Program Management

As initial attack organizations grow, questions arise about the appropriate level of "overhead" and support. Developing a system based on the concept of "what management and support structure is appropriate for this budget and preparedness force" is something that needs exploration. The U.S. Department of Interior uses a system called FIREPRO. A part of FIREPRO defines an overhead

structure based on workload and program complexity. A project that looks at organization structure will have value in future fire planning systems.

Conclusion

The National Fire Management Analysis System (NFMAS) is working well, but it can be enhanced. New analysis products, the use of new technology, and software engineering will increase the effectiveness of the NFMAS to answer questions and plan for the future. Research scientists, software engineers, economists, academics, and agency personnel should be working together to build the next generation fire planning tool.

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Sensitivity of National Fire Management Analysis System (NFMAS) Solutions to Changes in Interagency Initial Attack (IIAA) Input Data¹

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Abstract

A sensitivity analysis was conducted of the National Fire Management Analysis System (NFMAS) to better understand the relationship between data input and model output. After consultations with fire managers and researchers, five input variables were selected for sensitization: unit mission costs, average acre costs, net value change, production rates, and escaped fire limits. A random sample of 23 National Forests was selected, according to the distribution of forests within regions and fire frequency classes, on the basis of historical fire data. Database tables were manipulated, with each variable increased and decreased at six levels (± 25 , ± 50 , and ± 100 percent). The Interagency Initial Attack Assessment (IIAA) model was run at each successive level, generating a new set of output, cost plus net value change (C+NVC), for each sensitized variable. Results were analyzed statistically, and production rates and average acre costs were found to be the most influential, while unit mission costs was least influential. In general, greater sensitivity changes resulted in greater changes in C+NVC.

The National Fire Management Analysis System (NFMAS) was designed in the late 1970's by Richard Chase, for use by the USDA Forest Service in strategic fire management and budget planning. It was later adopted by other fire-management agencies, including the USDI's Bureau of Land Management and the National Park Service. The NFMAS simulation model (NARTC 1997) currently consists of two software programs: Personal Computer Historical Analysis (PCHA), which provides historical weather and fire behavior data, and the Interagency Initial Attack Assessment (IIAA). IIAA (COMPUS 1997) is the analytical engine, a tool intended to help analyze various fire-management scenarios or program options that represent various combinations of fire-fighting resources and other budget items. The overriding purpose of IIAA analysis is to help identify the most efficient level (MEL) of funding for a given National Forest, that is, the program option associated with lowest sum of the presuppression budget, emergency fire-suppression costs, and net value change of resources (the sum of positive and negative resource effects). An administrative unit's initial attack organization will use these data in developing budget requests. NFMAS is applied to a sub-forest area, the fire management zone, and results are aggregated to produce Forest, Forest Service Region, and agency-wide totals. This service-wide total is used as the basis for budget proposals.

Management of NFMAS is a major undertaking in the Forest Service. Training sessions are held at the Marana, Arizona, facility. NFMAS training is received by selected Forest Service personnel, ranging from district fire management officers to upper level managers, and by personnel from USDI agencies and various state fire-fighting organizations. A NFMAS "certification" process is implemented at both the regional and forest levels. Certification involves inspection teams reviewing and revising data and procedures used by field personnel to help ensure compliance with national policy, promoting consistency between units. NFMAS-related databases are constructed, calibrated, and analyzed to identify the most efficient initial attack organization for each Forest. The budgets associated with those most-efficient organizations, MEL, become part of the Forest Service appropriations process.

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Because the NFMAS process is a key management tool in the Forest Service and requires a substantial commitment of resources, it is important to understand its analytical workings, including how those workings and related information affect NFMAS solutions. However, surprisingly little formal attention has been paid to this matter. Smith (1985) investigated how changes in output values affected identification of the optimal fire management program, while Dimitrakopoulos (1985) focused on changes in fire behavior data, production rates, initial attack time, and fire size at discovery. Although both studies were limited to the Stanislaus National Forest, expansion would have been very difficult. Until recently, NFMAS software was not conducive to a rigorous sensitivity analysis because the software was extensive and not user-friendly. Indeed, after a quarter century of NFMAS, Bell and others (1995) recognized the need to know more about NFMAS' operations and called for a sensitivity analysis.

This study assesses the sensitivity of NFMAS solutions to changes in input variables, and it measures sensitivity in terms of change in cost plus net value change (C+NVC), the major quantitative output produced by NFMAS.

Methods

This study used a very straightforward approach. We selected a set of five IIAA variables to evaluate a sample of National Forests. NFMAS databases were obtained, manipulated as appropriate, and several hundred IIAA computer runs conducted. Resulting changes in C+NVC were noted and statistically analyzed to detect differences between variables and the level of sensitization.

Data Collection

The National Forest was chosen as the sampling unit. There are 156 proclaimed National Forests in the National Forest System, and roughly 116 National Forest administrative units (combinations of proclaimed National Forests) that correspond to the NFMAS concept of a "planning unit." We selected a random sample of 27 administrative Forests nationally, in proportion to their occurrence within Forest Service regions and fire frequency classes (low, medium, and high) based on 1992-96 fire occurrence data (Bunton 1997). However, because of significant differences in the completion status of current-year NFMAS analyses using the new Windows version³ of NFMAS (COMPUS 1996), several National Forest databases in our sample could not be obtained (to qualify for study use, Forest-level IIAA databases had to have been "calibrated"). Consequently, all Forests in the Pacific Southwest Region (Region 5) were excluded, as well as some Forests in the Rocky Mountain Region (Region 2) and the Pacific Northwest Region (Region 6). The Alaska Region (Region 10) does not use IIAA, because of very low fire frequency, and was not included in this study. Our final sample size was 23 National Forests.

We obtained the appropriate IIAA databases from each sampled Forest and identified the set of program options to use in the sensitivity analysis. We wanted to assess several program options in order to ensure a mix of options representing the range of program choices available to fire managers. Fortunately, most Forest databases we obtained contained this mix. Following national and regional directives for certification, each Forest developed five program options around an option and budget that describes the most efficient use of resources for presuppression activities. This "most efficient" program option, MEL, corresponds to the budget resulting in the lowest combined C+NVC upon natural resources, as a result of fire suppression activities. The remaining five program options are developed by increasing or decreasing the budget associated with the MEL option in increments of 10 percent, with each producing a new C+NVC. We, therefore, worked with six program options: MEL, M10 (MEL minus 10 percent), M20, M30, M40, and P10 (MEL plus 10 percent).

³Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

Although most sampled Forests conformed to the directive of predetermined 10 percent increments, there were a few exceptions. Additionally, only five options were submitted in one sampled Forest, while another contained an M40 presuppression budget about equal to its M10 budget. All databases were acquired from Forest-level personnel who provided valuable assistance with interpretation and questions. Databases obtained were opened by Microsoft Access software (Jennings 1997), and any compatibility problems encountered were resolved before sensitivity analysis proceeded.

Variables Sensitized

The dependent variable in this study was the change in C+NVC resulting from systematic changes in IIAA input variables. The NFMAS program includes software modules, PCHA and IIAA, each with an associated database. Much of the information contained in the PCHA database consists of historical weather and fire information, and these data are used by the IIAA software at the "calibration" stage. Calibration is the process by which outputs from the IIAA model are synchronized with the actual fire history during this predetermined period. All databases received from sampled Forests contained calibrated data. Selection of PCHA variables or IIAA variables affected by the calibration process was avoided, in order not to compromise calibration results.

At the initial stages of variable selection, we identified more than a dozen candidate variables on the basis of interest expressed by study-related personnel and previous studies. For example, several persons were interested in the sensitivity of NFMAS solutions relative to output values at risk; the contention being that IIAA solutions did not vary with changes in timber values. Similarly, we considered some variables that others used in similar analyses. For example, Smith (1985) evaluated both individual and groups of output values, while Dimitrakopoulos (1985) assessed production rates and fire behavior parameters. In the end, five variables were chosen for sensitization: average acre costs (AAC), unit mission costs (UMC), net value change (NVC), production rates (PR), and escaped fire limits (EFL). The escaped fire limits variable was actually two variables working in concert: acres burned (size) and fire duration (time). Conversely, the NVC variable consolidated several individual value-related measures, including stumpage values, into an overall net value per acre.

Sensitization Process

To establish a baseline for comparison, the IIAA model was run for each Forest with the original data and C+NVC results were recorded. Results of these initial IIAA runs were treated as "base" runs, against which all subsequent sensitivity runs were compared. Except for PR and EFL, the base-run values for each variable were sensitized at six levels: ± 25 , ± 50 , and ± 100 percent. PR and EFL were not sensitized at -100 percent because those levels are not meaningful and C+NVC results were grossly distorted.

Sensitizing variables in IIAA was done through use of the Microsoft Access database management tool. Each variable was sensitized through a series of database queries; we accessed and made changes directly to IIAA database tables, rather than using IIAA data-entry software to effect database changes. To reduce implicit rounding errors, target variable data were set to decimal places of 1/10,000. An update query transformed the target variable by the desired amounts.

Sometimes, a changed variable would produce unexpected outcomes. For example, we might change a database table, run IIAA, and find no change in output. We learned that IIAA software provides for automatic updating (recalculation) of several key tables after underlying information has been changed. This is accomplished by an auto-recalculate toggle set to "on" or "off," the default setting being "on." The Master Resource Table (MRT) is this type of table and its automatic updating can save the analyst a considerable amount of

work. Data in the MRT, not the underlying information, is used by IIAA in calculations. However, an analyst can edit MRT values to produce the desired information. When IIAA is run, the MRT is recalculated unless the auto-recalculation toggle is set to "off" before run execution. If auto-recalculate is "on," the MRT used in calculations may not be the same as the MRT as sent by the Forest, and the original database would be corrupted. After discovering this problem, and after several discussions with Howard Roose (Lolo National Forest) and Jim Bailey (COMPUS SRVC CORP), we decided no automatic recalculations be performed for either the MRT or the Option Selector Table in the model run. Whether the MRT (as sent to us) was the result of auto-recalculations or manual editing, this approach preserved the integrity of the original data to accurately reflect the unique fire budget situation of each sampled Forest.

IIAA was run for all fire management zones (FMZ's) within selected budget options, yielding a total of 713 computer runs (=23 forests times 5 variables times 6 sensitivity levels plus 23 base runs), with output reports generated for each run. The Option Summary Report format was selected as the primary output report because it contains information regarding C+NVC for the total run group (in this case, six program budget options), summed over all FMZ's. Results were copied into a spreadsheet where calculations of sensitivity and percent change were assessed.

Statistical analyses were at the same time very complicated and very simple. They were complicated because of the way databases were sampled and selected. They were simple because our analytical needs were modest. Analytically, we were interested in hypotheses relating to three questions: are there any differences in sensitivity among the variables tested; does the amount of sensitivity vary with the degree of sensitization; and is there an interaction between variable and the degree of sensitization? To properly test these hypotheses, the error mean square used is that associated with the full or "saturated" model (Neter and others 1990). The full analytical design corresponded to a four-factor analysis of variance, where the factors were: variable (the five variables chosen for sensitization); sensitivity level (the six levels of ± 25 , ± 50 , and ± 100 percent); fire frequency (the three levels of low, medium, and high); and program option (the six levels of M10, M20, M30, M40, MEL, and P10). After accounting for main effects and all two-, three-, and four-way interactions, we expected about 3,800 "total" degrees of freedom and about 3,300 "error" degrees of freedom.

Results

This study set out to determine the effect of varying the magnitude of several NFMAS-based variables on the C+NVC portion of IIAA output. Average acre costs (AAC), unit mission costs (UMC), net value change (NVC), production rates (PR), and escaped fire limits (EFL) were selected for analysis. The magnitude of each variable was sensitized ± 25 , ± 50 , and ± 100 percent, and results were compared to those resulting from the original values (the "base" run). The PR and EFL variables were not sensitized at the -100 percent level because these values have little meaning in IIAA and do not reflect real world situations. C+NVC change results were obtained for a random sample of 23 National Forests.

ANOVA Results

Although the overriding interest in this study pertained to the sensitivity of C+NVC to changes in the information used in IIAA, our results necessarily reflect other aspects of study design, including the variables chosen for study (factor A-Variables), the historical fire frequency for sampled forests (factor B-Frequency), the sensitivity level (factor C-Levels), and the program options (factor D-Options). Analysis of variance (ANOVA) results were obtained and analyzed (*table 1*).

Table 1—Analysis of variance for NFMAS sensitivity results.

Source	Sum of squares	Degrees of freedom	Mean square	F	P level
Intercept	737	1	737	5.1	0.024
A-Variables	7,598	4	1,900	3.1	<0.001
B-Frequency					0.864
C-Levels	160,346	5	32,069	220.8	<0.001
D-Options	1,335	5	267	1.8	0.102
A x B	528	8	66	0.5	0.888
A x C	582,813	18	32,379	222.9	<0.001
A x D	14,651	20	733	5.0	<0.001
A x B x C					<0.001
A x B x D					0.996
A x C x D	37,040	90	412	2.8	<0.001
A x B x C x D					1.000
Others					
Error	78,822	3,296	145		
Total	1,569,319	3,800			

In the typical factorial design, interpretation of the ANOVA begins with the interaction terms, thereby assessing the prospects of additive main effects. Although the overall four-way interaction (A x B x C x D) is nonsignificant, as are most other interactions involving fire frequency (factor B), the other relevant interactions are all significant (i.e., P level < 0.001). Significant interactions mean that the main effects are not simply additive and must be assessed in light of each other. The statistical significance we found was altogether expected, in light of the substantial degrees of freedom and the error mean square. More unexpected are the nonsignificant interactions involving the fire frequency variable (factor B).

Before dealing with the complications resulting from the interaction of factors, we set the stage by first dealing with the main issue: which variable is most influential? The average of the percent changes (labeled "normal") and the average of the absolute value of the percent changes were determined:

	Average Percent Change	
	Normal	Absolute
Unit mission cost	0.00033	2.1
Average acre cost	0.00024	19.1
Net value change	0.00081	12.4
Production rate	-0.334	21.0
Escaped fire limits	3.5	7.8

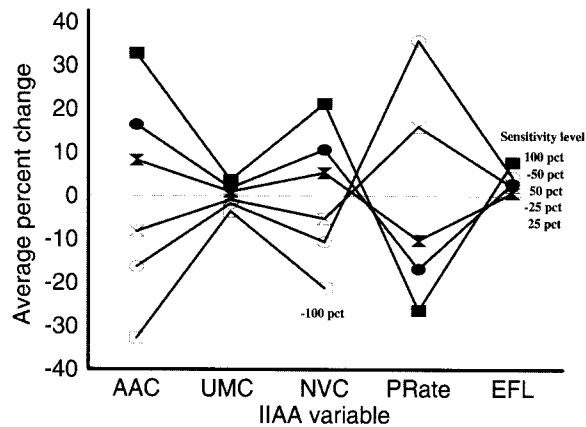
The "normal" percent change is simply the difference between a base C+NVC and that resulting from a sensitized variable, expressed as a percent of the base. The "absolute" percent change is simply the absolute value of the "normal" percent change. The distinction is important. Because we sensitized variables to ± 25 , ± 50 , and ± 100 percent and some of the variables were very symmetrical in their response, their average change was close to zero. Although that average concealed the sensitivity issue, the average of the absolute changes correctly revealed sensitivity. The average change produced by AAC, NVC, and UMC was nearly zero, while the other variables did not show that type of symmetry. However, as reflected by the absolute average percentage change, PR and AAC are the most influential, the NVC variable is next most influential, followed by EFL and UMC, in that order.

Variable by Sensitivity Level Interaction

Because of the significant interactions (*table 1*), the influence of the Variables (factor A) on changes in C+NVC should be interpreted in light of the other factors. In the case of the level of sensitization (factor C-Levels), the interaction with the target variable (factor A-Variables) helps clarify the importance of that

Figure 1

Average percent change in C+NVC, by IIAA variable and sensitivity level.



factor. The average percentage change was determined from the base C+NVC for each variable as it is sensitized to ± 25 , ± 50 , and ± 100 percent (*fig. 1*). The general size of the range of outcomes for each variable is quite compatible with the magnitude of the absolute average percent change. For example, the ranges shown for AAC and PR are the largest, as are the absolute percent changes. The ranges for UMC and EFL are the smallest, as are the absolute percent changes.

The symmetrical nature of changes for AAC, UMC, and NVC explains why their "normal" average percent change (in the listing) is nearly zero. For these variables, a change of -25, -50, and -100 percent has an equal but opposite effect on C+NVC compared to their positive counterparts. Consequently, the average percent changes for the six sensitivity levels, is close to zero. On the other hand, results for PR and EFL show no such symmetry. Results for PR are positive and negative, but skewed toward the positive. Results for all EFL variations are positive. The statistically significant A x C (Variables by Levels) interaction (*table 1*) result from the converging and diverging lines for AAC, UMC, and NVC, the reversal for PR, and the positive-only results for EFL.

Variable by Program Option Interaction

The ANOVA shown indicates a statistically significant interaction between Variables (factor A) and program Options (factor D) (*table 1*). The basis for that interaction is shown in *figure 2*. For example, the average percent change for AAC for each program option (i.e., M40-P10) is about zero, portrayed by all program option labels being stacked on each other. The same is true for UMC and NVC, again because of the symmetrical response to sensitization.

The major sources for the interaction between Variables and program Options (A x D) resides with the PR and EFL variables. In the case of PR, the overall averages are not 0 because changes in production rates have a differential effect on C+NVC. Specifically, for a pair of equal and opposites changes (e.g., ± 25 percent), the negative change (-25 percent) has a larger positive effect on C+NVC than the negative effect resulting from a positive change (25 percent), and the amount of that differential changes as program Option goes from M40 to P10. This results in negative average percent changes for M20, M30, and M40 and positive average changes for M10, MEL, and P10. All average percent changes for EFL are positive, regardless of whether the escape limits were increased or decreased (*fig. 1*). The overall consequence of these changes is most pronounced in the M40 program option and generally decreases to the P10 option (*fig. 2*; these results are affected by the fact that PR and EFL were sensitized +100 percent, but not -100 percent). If sensitization were restricted to ± 25 and ± 50 percent, PR results would all be positive and EFL results would remain positive but compressed.

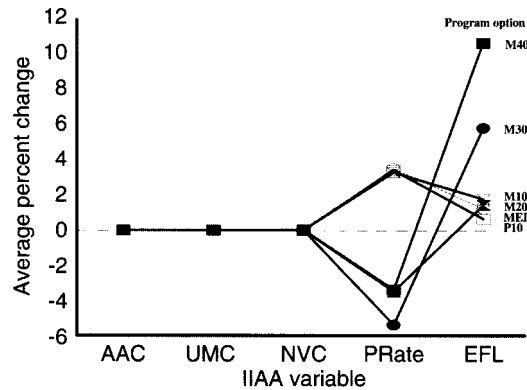


Figure 2

Average percent change in C+NVC, by IIAA variable and program option.

Individual Variables

More than interaction between variables and sensitivity levels or program options, the study was concerned with how changes in individual variables affected C+NVC. Unit mission costs had the smallest effect and production rates had the largest effect.

Unit Mission Costs

In addition to AAC, UMC constitute total emergency fire suppression costs. UMCs are intended to represent the typical average, emergency fire suppression costs of **containing** smaller, non-escaped fires. UMC are specified on a "per fire" basis for each producer line item (units that fight fires) and budget line item (types of money represented in program option budgets). For initial attack units, UMC represents the average cost per trip for use of that unit on contained fires. UMC only reflects costs paid out of emergency fire suppression funds, not budgeted costs or pay.

The user enters several bits of UMC-related information in several, IIAA data-entry screens. Data entry begins with identifying and describing producer types, but mainly involves editing several data fields in a series of line-item screens. Through these screens, IIAA collects information on equipment, personnel, supplies, rent, and other costs. Information is stored in various database tables, most notably the LineItems table. Then, in the process of running IIAA, the UMC values in the MRT are updated for final calculations. We sensitized the UMC variable in the MRT database table. In order to preserve the integrity of our newly sensitized UMC values, the toggle for automatic recalculation of the MRT was set to off before IIAA was run.

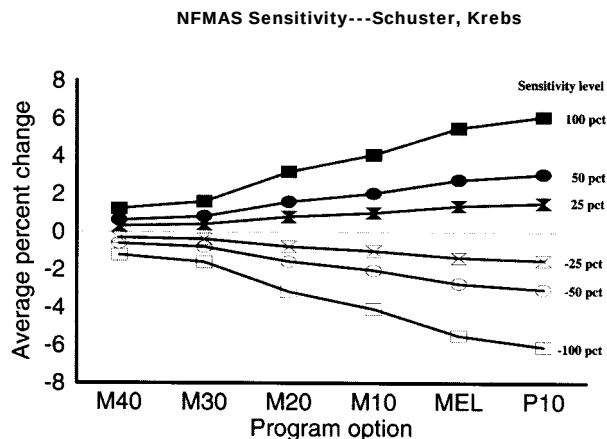
As shown earlier, changes in the UMC variable had the smallest effect on C+NVC, with an absolute average change of about 2 percent. C+NVC changed under all sensitivity levels and program options (*fig. 3*). If the absolute value of all points in *figure 3* were summed and divided by 36, the average would be about 2 percent. C+NVC responses to changes in UMC are symmetrical. In other words, changes above the zero line are mirror images of those below. However, the magnitude of C+NVC change varies with the program option level. The smallest responses are associated with the least costly program option, M40, a program option that is 40 percent less expensive than the MEL option. The largest C+NVC responses are for the P10 program option. If program options were funded at the MEL level, variations in UMC would have about the biggest effects possible.

Average Acre Costs

AAC are one of two costs comprising total emergency fire suppression costs, the other being UMC. AAC are specified for each fire size class, for each fire management zone. For size classes at or below the escaped fire size limit, AAC include **after-containment**

Figure 3

Average percent change in C+NVC for UMC, by program option and sensitivity level.



suppression costs that are not specific to the initial attack unit; that is, these AAC do not include UMC. For size classes above the escaped fire size limit, AAC includes all suppression costs (with UMC).

The user directly enters AAC information on the Average Acre Cost data-entry screen of IIAA. These costs are entered for the upper boundary of each fire size class within each fire management zone. HAA takes these data and stores them as the Cost variable in the AAC database table. To sensitize AAC, we varied the Cost variable and ran the IIAA model.

The AAC variable was shown earlier to have the second largest effect on changes in C+NVC, with an absolute average change of about 19 percent. C+NVC changed under all sensitivity levels and program options (*fig. 4*). If the absolute value of all points in *figure 4* were summed and divided by 36, the average would be about 19 percent. As with UMC, C+NVC responses to changes in AAC are symmetrical. In other words, changes above the zero line are mirror images of those below. However, the magnitude of C+NVC change also varies with the program option level. But the direction of change is opposite of UMC. The smallest responses are associated with the most costly program option, P10, a program option that is 10 percent more expensive than the MEL option. The largest C+NVC responses are for the M40 program option. If program options were funded at the MEL level, variations in AAC would have about the smallest effects possible.

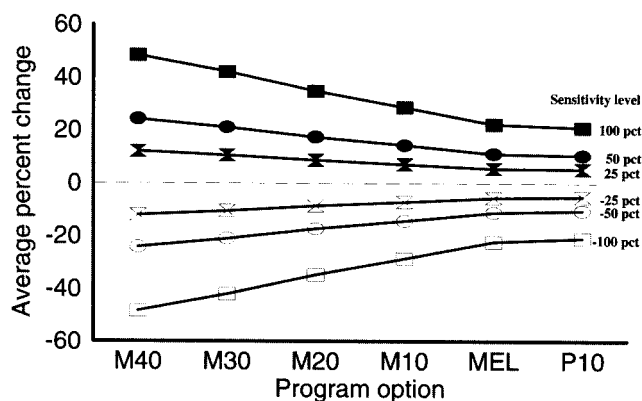
Net Value Change

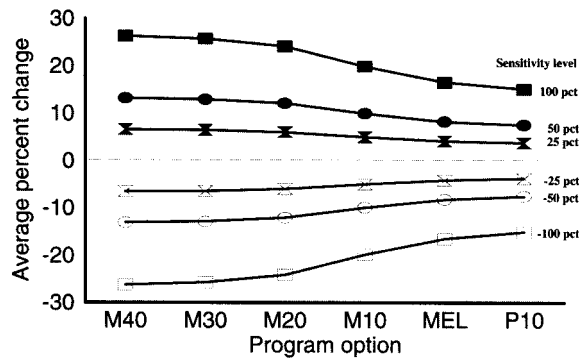
NFMAS uses the concept of "net value change" in two ways. First, it is used as a component of IIAA output, as in C+NVC. In that sense, net value change refers to the sum of positive and negative changes in outputs resulting from fires, over a geographical area such as an FMZ. Second, net value change is a variable (NVC) used in the IIAA model to measure the economic impact (per acre) of fire on resource outputs, both positive or negative effects. We focus on the NVC variable. Outputs can be market-valued or valued outside markets.

The user enters NVC-related information through several data-entry screens in IIAA. For example, the unit value of recreation or forage can be entered in the Setup NVC Tables screen, which also accepts pre- and post-fire output

Figure 4

Average percent change in C+NVC for AAC, by program option and sensitivity level.



**Figure 5**

Average percent change in C+NVC for NVC, by program option and sensitivity level.

information. A series of data-entry screens are also used to collect timber-related information, including stumpage values and volumes, as well as fire mortality and salvage rates. IIAA stores NVC-related information in several database tables. It also performs numerous calculations on these data, all intended to portray the net (pre- versus post-fire) consequences to resource output values resulting from fires. These net values are expressed on a per-acre basis, and are stored as the WPANRVCBF variable in the NVCTab1e database. Used in all IIAA calculations, we accessed the WPANRVCBF variable, sensitized it, and executed the IIAA model.

Of the five variables we evaluated, changes in the NVC variable had the middle effect on C+NVC, with an absolute average change of about 12 percent. C+NVC changed under all sensitivity levels and program options (*fig. 5*). If the absolute value of all points in *figure 5* were summed and divided by 36, the average would be about 12 percent. C+NVC responses to changes in the NVC variable are symmetric. That is, changes above the zero line are mirror images of those below. However, as with AAC, the magnitude of C+NVC change varies with the program option level. The largest responses are associated with the least costly program option, M40, a program option that is 40 percent less expensive than the MEL option. The smallest C+NVC responses are for the P10 program option. If program options were funded at the MEL level, variations in NVC would have some of the smallest effects possible.

Production Rates

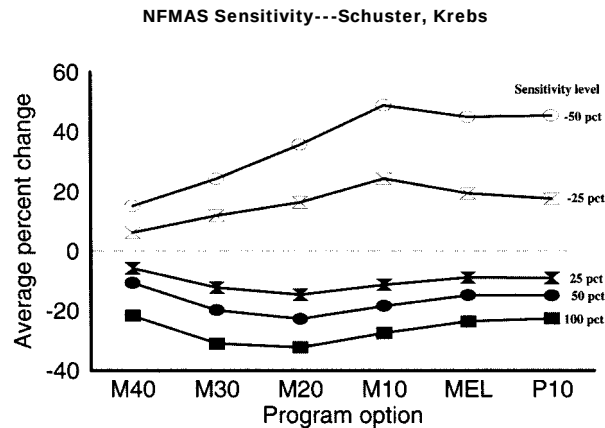
The rate at which fireline is produced by initial attack units are called "production rates" (PR). Rates are measured in chains per hour for ground forces and gallons per 100 feet of fireline for aerial-delivery forces. PR are specified for each initial attack unit, and reflect fire perimeter containment capabilities, not capabilities for sustained fireline construction. "Standard" rates have been developed for various types of initial attack units.

Production rates are specified in two ways. First, they can be entered directly into the default production rates screen in IIAA. This screen is normally accessed when national, standard production rates are used in conjunction with IIAA's automatic calculation of the MRT. Second, the user can edit these production rates in the user-viewable MRT that were created by using the auto-MRT provision of IIAA. Regardless, production rates found in the PRate variable of the MRT database table are used in IIAA calculations. We sensitized PRate (our PR variable), set the auto-MRT toggle to "off," and ran IIAA.

Changes in the PR variable had the largest effect on C+NVC of any variable studied, with an absolute average change of about 21 percent. C+NVC changed under all sensitivity levels and program options, except the -100 percent level (*fig. 6*). If the absolute value of all points in *figure 6* were summed and divided by 30, the average would be about 21 percent. C+NVC responses to changes in PR are not symmetrical. Negative change to PR has a larger effect on C+NVC changes

Figure 6

Average percent change in C+NVC for PR, by program option and sensitivity level.



than do equivalent, positive changes. Moreover, that differential is smallest at the M40 program option and generally increases with more costly options. At the same time, the overall magnitude of C+NVC change varies with the program option level, but C+NVC responds to positive changes differently than to negative changes. In both cases, the smallest responses are associated with the least costly program option, M40. The largest C+NVC responses for positive changes in PR are at the M20 program option, while the M10 option shows the largest responses to negative changes. If program options were funded at the MEL level, variations in PR would have relatively large effects in C+NVC.

Escaped Fire Limits

The point at which a fire is declared "escaped" is specified in IIAA by a fire size or duration limit. Escape "acres" is the fire size limit, in acres, after which a fire is assumed to have escaped initial attack; escape "hours" is the time limit equivalent. When a fire escapes, the ultimate size the fire achieves, in Forest Service analyses, is determined by the Escaped Fire Table in IIAA. Specified for each fire management zone, final fire sizes are listed for combinations of fire intensity levels and representative locations. Once the final size has been determined, the Average Acre Cost database table is used to specify the per-acre suppression costs.

The user directly specifies escaped fire limits for each fire management zone through the Fire Management Zones data-entry screen of IIAA, but much more information needs to be synchronized. First, the escaped fire acre limits need to be reflected both in the upper acre limit boundaries in the Average Acre Cost data-entry screen and in the costs per acre entered. Specifically, costs per acre up to the escaped fire limits do not include unit mission costs while costs per acre above the limit include UMC. Second, the escaped fire acres limit must be reflected in the acre boundaries in the Escaped Fire Table in IIAA. We had to synchronize these items every time it was changed. Accordingly, we modified the EscAcres and EscHours variables in the FMZ database table; the UpAcres variable in the AAC database table; and the Acres50 and Acres90 variables in the EFT database table. In the process of making these changes to databases from sampled Forests, we encountered a range of questionable situations, including size-class boundaries not synchronized with escaped fire limits and average acre costs that always increased, always decreased, decreased and increased, and increased and decreased.

Overall, the EFL variable had relatively little effect on C+NVC, with an absolute average change of about 8 percent. C+NVC changed under all sensitivity levels and program options, except the -100 percent level (*fig. 7*). If the absolute value of all points in *figure 7* were summed and divided by 30, the average would be about 8 percent. C+NVC responses to changes in EFL is not only not symmetrical, but it is almost random. The largest effects take place at the M40 and M30 program levels, where a plausible ordering of effect is shown: +100, +50, +25, -25, and -50 percent. Beyond the M30 program option, several

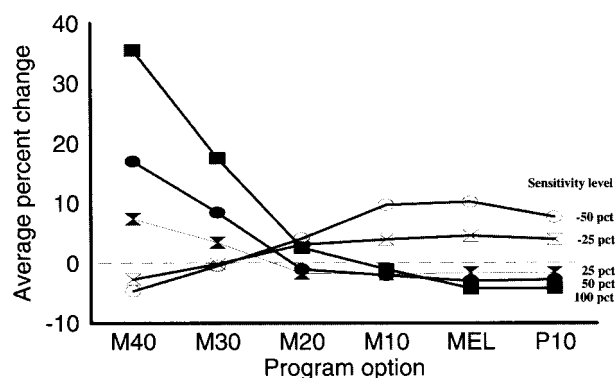


Figure 7

Average percent change in C+NVC for EFL, by program option and sensitivity level.

crossovers occur, such that the ordering at P10 is the total opposite of before: -50, -25, +25, +50, and +100 percent. We cannot interpret the meaning of these reversals but believe it is related to the questionable information we encountered.

Discussion

This study set out to determine which IIAA-based variable and what amount of change in the variable would have the greatest effect on IIAA results, as measured by C+NVC. In terms of the variables we examined, the answer is clear: PR and AAC are most influential; EFL and UMC are least influential; and the NVC variable is in the middle. In terms of the level of variable change, the more the change (positive or negative), the bigger the effect, generally. However, there was no consistent pattern of program option effect. Sometimes changes in the variables had a large effect on C+NVC with costly program options such as MEL and P10; sometimes the largest effects occurred at the least costly levels of M40 or M30.

The most immediate application of these results is probably in training and research. NFMAS training sessions should use these results to guide instruction. Students could be made more aware of how errors in information can influence IIAA results. Instructors could concentrate more on influential variables and spend less time discussing variables that have little effect on C+NVC. These results could also influence research by emphasizing the need to improve information about variables that influence IIAA outcomes. Similarly, forest planners could concentrate efforts on compiling more refined values for those variables that have the greatest effect on C+NVC outcomes.

Future investigations into the operation of IIAA and its sensitivity to changes in variables could focus on several options. First, we could continue the current study in order to collect and complete IIAA runs on the original sampled forests. Because sampled forests did not have their IIAA databases completed when needed in this study, Region 5 was completely excluded, and Regions 2 and 6 under-represented. Second, we could expand the study to include more observations, by increasing the number of sampled forests beyond the original study plan. This would give a more adequate sample from which to better confirm the relationships now found and delve more deeply into cause-effect issues. Third, we could add additional variables and measure C+NVC sensitivity to systematic changes in them. When we originally selected variables, we identified more than a dozen candidates. Some were eventually discarded or combined with other variables. If desired, we could disaggregate these aggregate variables and investigate the component variables, we could add new variables from those discarded, or we could identify new variables. Fourth, we could expand the study to involve other agencies that use NFMAS, such as the USDI-BLM and Bureau of Indian Affairs. Because NFMAS is used by several Federal and State agencies in addition to the Forest Service, our results should be tested against procedures and budget allocation processes for other NFMAS users. Fifth, we could expand the orientation of this study to focus on how budget allocations and/or the MEL program option changes with changes in IIAA variables.

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An Overview of Leopards: The Level of Protection Analysis System¹

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Abstract

The Level of Protection Analysis System (LEOPARDS) allows the structured assessment of the outcomes and costs associated with alternative fire management policies, budgets, and suppression resource mixes. Its primary component is a deterministic, spatially conscious simulation model that emulates the daily fire suppression activities of a provincial fire management agency. Inputs for the model include historical fire weather and fire occurrence data, land-use objectives and operational rules, and infrastructure and suppression resource information. The model estimates physical outcomes (e.g., response time, number of escaped fires, area burned), fiscal results (e.g., fixed and variable costs), and resource utilization information. LEOPARDS has been used to address a number of strategic fire management issues in the province of Ontario and is being assessed for use in other parts of Canada.

Introduction

The Forest Fire Management Program of the Ontario Ministry of Natural Resources is responsible for providing forest fire management and protection to more than 85 million ha of the crown land in Ontario. Currently, Ontario annually spends an average of \$85 million directly on fire management to respond to 1,761 fires, which burn 276,309 ha of forested land (less than 80,000 ha of which is intensively protected commercial forest).

Given the increasing complexity and cost of fire management, governments and fire managers are seeking techniques to systematically assess ways that fire management programs can efficiently reduce the detrimental social, economic, and biological impacts of forest fires. This has been called level of protection analysis (Martell and Boychuk 1997). In its broadest sense, level of protection refers to the amount of effort that an agency is willing to expend to respond to forest fires on the basis of its land and resource management objectives. This relationship can be depicted conceptually (equation 1), showing that the physical outcomes of forest fires (e.g., area burned, societal impact) are a function of the fire load (i.e., number, size, and intensity of fires) and suppression effort, which can be quantified in terms of dollars invested in fire suppression.

$$\frac{\text{fire load}}{\text{investment in fire suppression}} \Leftrightarrow \text{outcome} \quad [1]$$

Hence, if a forested area is subjected to an increase in its fire load while the investment in suppression remains constant, the outcomes will be more severe. On the other hand, an increased investment in fire suppression will, in theory, reduce outcomes (e.g., area burned) if the fire load remains constant. To determine the economic, social, and/or environmental impact of forest fires, these physical outcomes must be translated into value change of the affected area and assessed within the context of the forest as a whole.

The Level of Protection Analysis System (LEOPARDS) is a decision analysis tool that can be used to predict the costs and impacts resulting from a set of fire management policies and budgets. It is primarily intended to address two types of questions:

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- **Policy and Budget Alternatives**-What are the costs and benefits associated with a change in fire protection zones or levels of protection? What are the costs and impacts of allowing more fires to burn with less suppression? What should be the size of the base and emergency fire fighting budgets? What is the potential impact of a budget reduction (or increase)? What types of outcomes could be expected if the budget provided for a significant increase in firefighters?
- **Suppression Resource Alternatives**-What is the most efficient mix of ground crews and airtankers that will enable the policy and budget objectives to be met? What are the benefits and costs of purchasing a new airtanker and what type of airtanker would be best for the local situation? Should there be more long-term helicopter contracts or should helicopters be hired on demand? What is the impact of closing or opening specific fire attack bases?

This paper provides a general overview of LEOPARDS by describing the structure and characteristics of the program, and it addresses strategic fire management questions in the province of Ontario and discusses development initiatives within Canada.

Structure

LEOPARDS is a computer-based decision support system that is similar in concept, but different in design, to other types of strategic fire management models, such as the National Fire Management Analysis System (USDA Forest Service 1985), the California Fire Economics System II (Fried and Gilles 1988), and the Aerial Delivery Firefighter Program (Wiitala 1998). The LEOPARDS model has evolved primarily from an initial attack model that was developed to evaluate airtanker requirements in Ontario in the early 1980's (Martell and others 1983, 1984). It also uses components of "LANIK" (Martell and others 1994), an extension of the original initial attack model produced in the early 1990's to allow more extensive analysis of level of protection issues. Active development and use of the current LEOPARDS model began in 1995 in Ontario in which the two earlier models were combined and extended into a new spatially conscious model.

LEOPARDS allows users to evaluate the effectiveness (physical results) and efficiency (fiscal results) of spatially explicit fire management objectives and suppression resource configurations. At the core of the program is a complex, deterministic initial attack simulation model that emulates the daily operational suppression activities of a provincial fire management agency (*fig. 1*). The simulation model requires three types of input (i.e., historical fire incidence and fire weather data, land-use objectives and operational rules, infrastructure and suppression resource information) and produces three forms of outputs (i.e., physical, fiscal, and resource utilization results). An important feature of LEOPARDS is that it accounts for the temporal queuing conflicts and spatial realities of forest fire suppression. In other words, it is sensitive to the problems that occur when there are multiple fire ignitions over a large area or a large number of fires in a small area in a short time period and only a limited number of suppression resources to attack them, which are situations that often lead to delays in initial attack and more fire escapes. Currently, the model does not simulate fire growth or suppression beyond the initial attack phase of suppression (i.e., until 10 a.m. the day following arrival); therefore, statistical techniques are used to estimate the total area burned based on the number of escaped fires.

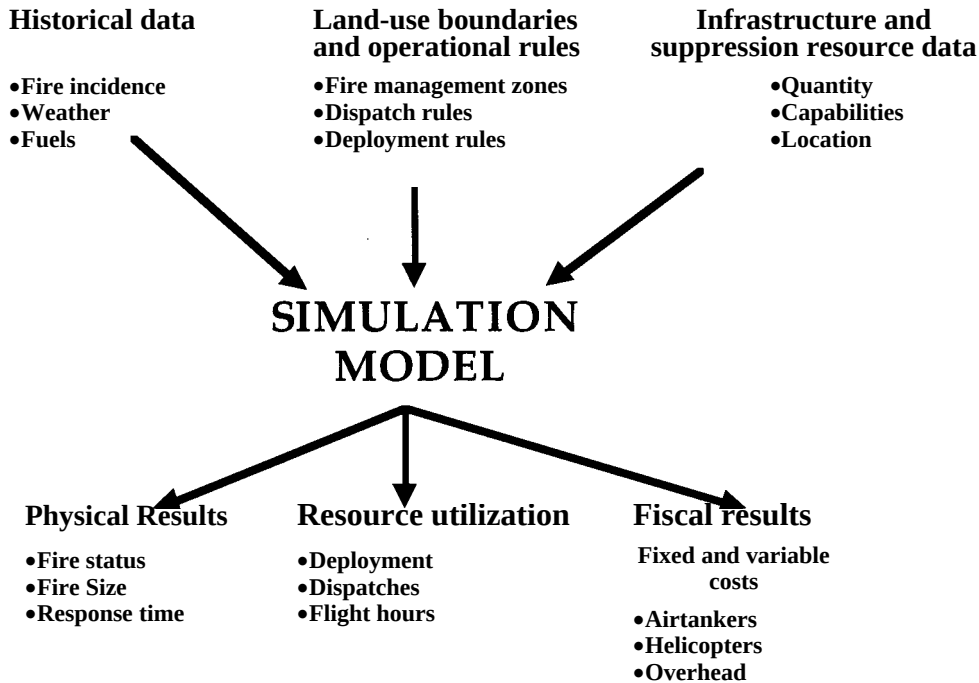


Figure 1

General structure of the LEOPARDS simulation model

Inputs

Several input files provide LEOPARDS spatial and non-spatial data. For instance, the province can be subdivided into any number of Fire Management Zones, each of which share common fire management strategies and general spatial characteristics (e.g., road access, distance to water). Each zone will have a specific set of initial attack dispatch rules that relate directly to the fire management policy for that zone. For example, in some parts of Ontario there are areas where fire is aggressively initial attacked because of the high values at risk (e.g., communities or valuable timber resources), and there are areas where fire is not attacked as aggressively because of lower values at risk or the view that fire can be beneficial.

Information in the Dispatch Rules defines the resources to be dispatched in each Fire Management Zone under different fire behavior conditions. These dispatch rules were derived through focus group sessions with experienced dispatchers. The focus group identified four criteria (rate of spread, fire size, flame length, and fuel type) upon which dispatch decisions are made. For each possible situation the group collectively identified the number of crews and airtankers they would dispatch and the desired response time objective given the fire management objectives within the area.

The Dynamic Deployment database file defines the type, location, operating cost, and capacity of each initial attack base. It also specifies the initial allotment of resources at each base at the start of the year as well as any constraints pertaining to resource deployment (e.g., a central base in a high value wildland-urban interface area might require at least one airtanker regardless of the fire danger conditions that exist in that area or elsewhere). Although LEOPARDS works through the fighting of fires on each day, this file tracks the movements and availability of resources from one day to the next.

Information about the capabilities and costs of various types of aircraft is contained in the Aircraft Attributes file. This includes firefighter transportation and water/retardant dropping capability; aircraft cruising and working speed; mobilization, take-off, scouting, dropping and landing times; fixed and variable costs; and operating constraints (e.g., maximum wind speeds). Currently the model allows up to four types of aircraft (including helicopters) to be specified.

The Airtanker Drop data file contains data from drop pattern analyses of different aircraft (George and Blakely 1973, Stechishen and others 1982) that

have been converted into fire line lengths of specific water depths. For example, a water drop from a CL-215 is able to create 226 feet (69 m) of line with a minimum water depth of 0.005 inches (0.002 cm), 220 feet (67 m) with a depth of 0.01 inches (0.003 cm), etc. (Australian Fire Authorities Council and Bombardier Inc. Canadair 1996). This type of data can be determined for both closed and open canopy fuels and is used in defining the effective line building rates of the airtankers.

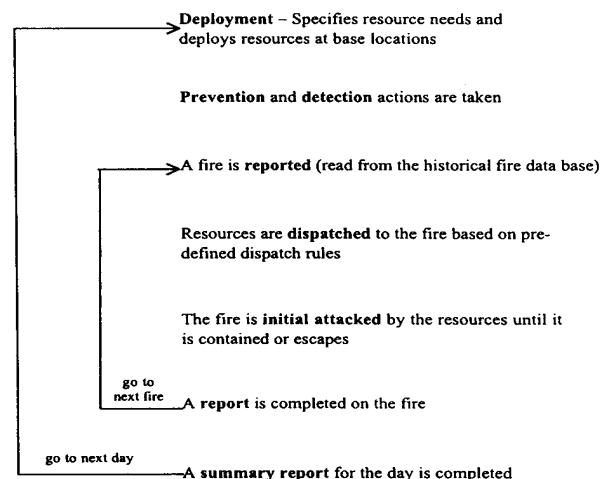
The Historical Fire data file contains spatial and temporal information about each fire used in the simulation. Historical fire records provide the location, time, cause, discovery size, fuel type, and fire behavior characteristics of each fire. Spatially interpolated, diurnally adjusted fire weather is used with the fuel type information to model the growth of each fire using the Canadian Forest Fire Behavior Prediction (FBP) System (Forestry Canada Fire Danger Group 1992). This set of historical data is assumed to be indicative of what can be anticipated in the future; therefore, a relatively long historical data record (e.g., 20 years) is likely to be more representative of the range of possible conditions than a short record (e.g., 2-3 years).

The Simulation Parameters file defines a wide range of variables that control the simulation. It also allows the user to specify the value of certain variables (e.g., temporary helicopter costs, standard crew size) and to test the sensitivity of specific assumptions and variables within the model (e.g., crew and airtanker line building productivity, detection size).

Simulation Process

LEOPARDS simulates the activities conducted by a typical fire management organization on a daily basis and on each fire (*fig. 2*). At the start of each new day a preparedness plan is implemented in which resources are deployed around the province. This deployment includes both aircraft and personnel and allows for the temporary hire and release of crews and helicopters as well as the inter-provincial sharing of airtankers.

Figure 2
Simulation process of LEOPARDS.



Prevention and detection activities follow deployment. The model uses a simple screening process that acts upon the historical fire incidence database to eliminate a proportion of the human-caused ignitions and/or change the initial fire discovery size. The detection screen is a multiplier that affects all fires by the same proportion (e.g., a doubling of the detection size). The prevention screen can target specific causal agents, locations, and the time of year as necessary. Relationships between financial investments in detection or prevention and the resulting change in detection size or number of ignitions are defined by the user.

After the detection of a fire, the model reads key information from the historical fire incidence database and then begins tracking the growth of the fire on the basis of the interpolated, diurnally adjusted fire weather / danger data and the fuel type at the point of ignition. The next step is to dispatch resources based on the predefined dispatch rules. Because the historical fire data is read sequentially, the model actions fires in chronological order. Available resources are sorted by time-proximity to the fire location and those resources that can arrive at the fire first are dispatched and assigned to the fire.

Once resources arrive at the fire, suppression activities begin. Fireline construction and fire growth are modelled simultaneously using Quintilio and Anderson's (1976) initial attack containment model, which captures the interaction between these two processes. Initial attack continues until the requirements for fire containment are met (e.g., 80 percent of the fire perimeter is contained --- a user defined criteria) or the fire is determined to have escaped. If the fire is contained, resources are returned to the nearest base and become available for another dispatch. If necessary, airtankers will return to base before a fire is contained to abide by flight constraints (e.g., low fuel, night, daily flying time restrictions). Firefighters remain at the fire for at least the remainder of the day and, depending on the time at which containment occurs, may stay a second day to complete mop-up activities. Once a fire escapes initial attack, airtankers return to base but firefighters can be detained up to 3 days. The simulation model does not currently attempt to model suppression activities on escaped fires but does allow some "draw down" or reduction in initial attack resources if a fire escapes. It is assumed that after 3 days, sustained action suppression resources will be in place, allowing the initial attack crews to return to their activities.

After the completion of the initial attack phase of each fire, a report is produced and stored for future analysis. The model works through each fire for each day and then produces a daily activity summary. The model then moves on to the next day by returning to the deployment phase. This looping through each fire and each day continues until all the fires on all the days in the historical database have completed.

User Interface and Program Design

The simulation program is currently embedded within ArcView⁴, a PC-based geographic information system (GIS). The GIS acts as a tabular, graphical, and spatial data input and analysis tool. The initial attack simulation model provides data to ArcView for analysis, or results can be ported to a statistical software program. The bulk of the simulation model is written in FORTRAN; however, more recently developed subroutines are written in C and LINDO.

Applications

LEOPARDS has been used extensively in the province of Ontario to help gain insights into a wide range of complex fire management problems. This is done by changing the model's inputs, running the simulation, and then examining the results within the context of the assumptions and limitations of the data and model. A few of the issues that have been addressed recently include: assessing the interaction of different fixed and variable budgets, identifying optimum levels of initial attack firefighters, comparison of fleet conversion of Canadair CL-215s, determining the benefits of using of ground foam, and changing the boundaries of Ontario's Fire Management Zones and altering the level of protection within those zones.

Relationship Between Fixed and Variable Suppression Costs

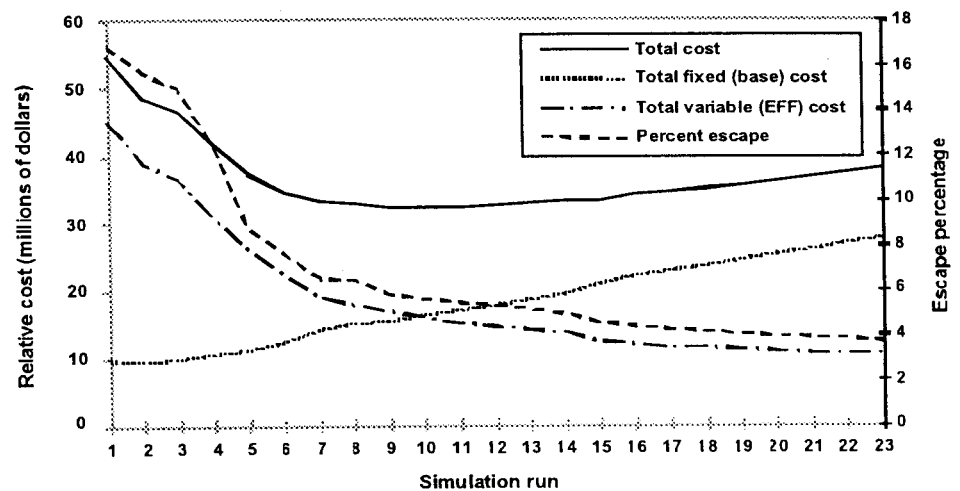
Theoretical models that relate fixed and variable fire suppression costs have existed for many years (Arnold 1949, Gorte and Gorte 1979, Sparhawk 1925). It is, however, difficult for a particular agency to thoroughly examine and quantify

⁴Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

this concept by using actual fire cost data because of the data's limited value range and changes in fire management policies and practices over time. These constraints can be overcome by using a simulation model like LEOPARDS. For instance, when the fixed (or presuppression) budget for the province of Ontario is increased, the variable costs decline (*fig. 3*). For each simulation run, the amount of fixed funding for suppression resources (full-time firefighters, airtankers, helicopters, attack bases, detection and prevention) was increased over a range of \$10 million to \$25 million. Initial increases in fixed cost investments yielded a rapid reduction in the percentage of escaped fires, variable costs, and total costs. The total cost curve suggests that there is an optimum fixed resource level (*fig. 3*); however, the "penalty" for minor departures is relatively small. For example in this scenario, there is little difference in the total cost even if the fixed budget varies from \$13 million to \$18 million. The total cost will also begin increasing when increases in fixed suppression expenditures have less impact on the percentage of escaped fires (e.g., simulation runs 15 to 23; *fig. 3*).

Figure 3

Relationship between fixed and variable spending; the percentage of escaped fires; and total fire management cost (generated from a series of LEOPARDS simulation runs, each one with progressively more suppression resources in a relatively proportionate balance).



Identifying the Optimum Number of Initial Attack Firefighters

A question frequently asked of and by fire managers in Ontario is "What is the optimum number of full-time initial attack firefighters for the province?" To address this question a series of simulation runs, each with a different number of firefighters, were made using LEOPARDS. The analysis was conducted based on the current attack base configuration, air attack resources (i.e., airtankers and air transport), and fire management zones and policies. Costs for seasonal and temporary out-of-province firefighters were provided. Constraints were placed on how fast temporary firefighters could be acquired, and it was assumed that they would be equally efficient at building fireline. For each scenario, the number of escaped fires was determined as well as the total fire management costs for the province. Given that LEOPARDS does not currently model sustained action fires, a statistical method based on historical information is used to determine the cost of an escaped fire, and this is incorporated into the total cost value derived for each scenario.

The model's results were determined for situations in which the number of firefighters in Ontario varied from 342 to 702 (*fig. 4*). There was a local minima between 390 and 440 firefighters, but when the number of firefighters exceeded this local minima, the total cost dropped to the true minima of 470 to 540 firefighters. The true minima is flat because the cost of the additional firefighters is offset by the saving incurred from fewer escape fires. This flatness also suggests the model is relatively cost-insensitive to changes in the number of firefighters over this range.

This information would suggest that the optimum number of firefighters would be between 475 and 550 (*fig. 4*), but there are other considerations that must be taken into account before reaching a final decision. For example, it is necessary to allow firefighters time off during the summer; this effectively multiplies the results by seven-fifths, increasing the optimum to 665 to 770 firefighters. It is also known that the current model does not incorporate uncertainty associated with fire occurrence and deployment; therefore, a buffer of firefighters (e.g., 40-60) should be added to the optimum.

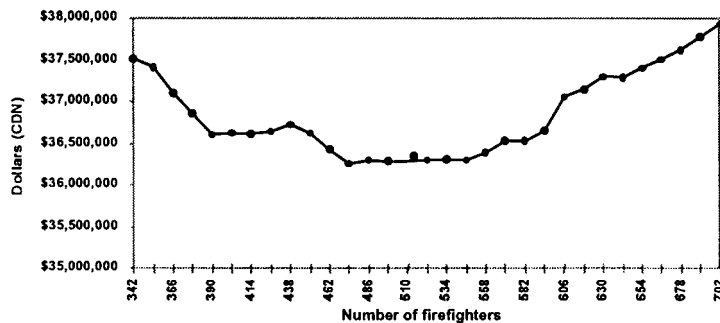


Figure 4

Total fire management costs for a series of LEOPARDS simulation runs with varying numbers of firefighters.

This analysis illustrates the importance of integrating the model results as they are produced with an understanding of the operating characteristics, assumptions, and limitations of the model. This analysis and subsequent interpretation was the basis for increasing the complement of initial attack firefighters in Ontario from 599 to 699 for the 1998 fire season with plans for a further increase to 750 firefighters in 1999.

Future Development

Although LEOPARDS has been used extensively and effectively in Ontario, work is continuing to further enhance and extend the model in two ways. First, procedures are being developed to include risk and uncertainty in the deployment component of the model so that it will more accurately reflect operational deployment activities and costs. Second, a new subroutine is being developed to extend LEOPARDS beyond the initial attack phase of fire suppression to include multi-day fire growth for escaped and non-actioned fires. This abstract simulation module will allow the assessment of alternative policies and strategies pertaining to large fires.

Nationally, LEOPARDS is being evaluated through the Canadian Forest Fire Centre (CIFFC) Fire Economics Working Group, to determine if the model can be adapted for use in other parts of Canada. This evaluation will identify modifications and additions that are necessary for the model to effectively reflect the varying forms for fire management policies and suppression activities present in different Canadian agencies. For example, in western Canada land-based retardant aircraft capable of making drops on multiple fires are commonly used, but this practice is not currently modelled in LEOPARDS. Modifications of this nature will require a re-assessment of the modelling procedures used in LEOPARDS and a re-engineering of the program to make it more versatile and adaptable.

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The Economic Efficiency of the National Fire Management Analysis System and FIREPRO¹

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Philip N. Omi²

Abstract

The economic efficiency of the National Fire Management Analysis System (NFMAS) and FIREPRO is examined. A brief history of the two programs is provided, as well as recent improvements to the contemporary theory of cost plus net value change (C+NVC). The NFMAS process is reviewed relative to the theory of C+NVC with particular focus on its ability to reliably locate the most efficient level (MEL) of preparedness/presuppression. FIREPRO is reviewed with regard to its ability to ensure cost effective resource allocations. Improvements and alternative approaches for both systems are suggested.

Introduction

The National Fire Management Analysis (NFMAS) is used by the USDA Forest Service and the Bureau of Land Management. FIREPRO is used by the National Park Service, and its related program FIREBASE is used by the Fish and Wildlife Service. These three programs provide key guidance in allocating management budgets. For example in 1994 the Forest Service spent nearly 1 billion dollars on fire management (Bell and others 1995). Thus, even small improvements in economic efficiency would have significant effects on the costs of fire management on public lands administered by these three agencies. This paper does not provide a comprehensive review of all parts of the two programs (Fried and Fried 1996). Instead, it examines how these programs conform to the theory of cost plus net value change (C+NVC).

Since the pioneering work of Sparhawk (1925), Hornby (1936) and Headley (1943), there has been a realization that at least in theory there is an optimal level of fire management effort. Implicit in this realization is that not all fires should be fought as aggressively as possible. Despite this ground breaking work, in 1935 the Forest Service adopted the "10:00 a.m. policy" (Gorte and Gorte 1979). This policy was adopted after two severe fire seasons in the Pacific Northwest.

The approved protection policy on the National Forests calls for fast, energetic, and thorough suppression of all fires in all locations, during possible dangerous fire weather.

When immediate control is not thus obtained, the policy then calls for the prompt calculating of the problems of the existing situation and probabilities of spread, and organizing to control every such fire within the first work period. Failing in this effort, the attack each succeeding day will be planned and executed with the aim, without reservation, of obtaining control before 10 o'clock in the next morning.

Interestingly, this policy was viewed by many at the time as not contradictory to the idea of economic efficiency (Hornby 1936). This policy continued into the 1970's. During the 1970's congressional budget requests by the Forest Service for fire fighting increased significantly without a concomitant decrease in suppression costs or damages. This resulted in Congress including a mandate for cost-benefit analysis in the 1979 appropriation (NFMAS Reference Material 1992).

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After this, the Forest Service developed NFMAS in 1979. At the heart of NFMAS is the theory of C+NVC, which was developed by Sparhawk (1925) some 55 years previously.

In the mid-1980's the National Park Service (NPS) developed the first version of its own system called FIREPRO. FIREPRO has gone through several incarnations, with the current version based on performance targets established in 1989 (NPS 1997). FIREPRO is a very different system than NFMAS, which is partly a result of the different philosophies of the two agencies. The NPS is charged with land stewardship and public enjoyment of resources rather than resource utilization. This is reflected in the architecture of FIREPRO, which does not consider resource values lost to fire. However, FIREPRO is designed to find the most cost efficient way of achieving program targets. While resource values are not considered directly in formulating these targets, FIREPRO is charged with finding the least cost to achieve them. Although these two models have differing objectives, they are both philosophically based on economic theory.

This paper examines the economic efficiency of the two most widely used fire management computer programs: NFMAS and FIREPRO. We also examine the mechanics of FIREPRO and NFMAS to illuminate their principles of operation. Data for NFMAS illustrative examples were drawn from the sample administrative unit data set that accompanies NFMAS. Data for FIREPRO examples were drawn from the 1999 budget request process. Although specific data sets are used, the conclusions drawn are generally applicable.

Recent Improvements to the Theory of C+NVC

Recently, it has been shown that the Sparhawk model, and those derived from it, are inappropriate representations of the fire management problem (Donovan and Rideout 1999). We demonstrated that in two-dimensional graphical representations of the model, too many inputs (both presuppression and suppression) are allowed to vary. If the x-axis is labeled presuppression (as is conventionally done) then suppression becomes a function of presuppression and becomes an output of the model rather than an input. It is shown that two conditions must hold in order for the true minimum of the C+NVC bowl to be identified:

1. Allow inputs (presuppression and suppression) to be independent and simultaneously modeled, but related through the production function, unless a formal functional dependence is established.
2. Two-dimensional illustrations including presuppression, suppression, and net value change need to hold one of these variables constant while viewing the relationship between the other two. Such a requirement is fundamental to properly carrying out partial sensitivity analysis, which is central to the way NFMAS identifies the most efficient level (MEL) of presuppression expenditure.

NFMAS

The National Fire Management Analysis System (NFMAS) is a computerized fire management and budgeting system. Interagency Initial Attack Assessment (IIAA) is its key computational component and is used to test different fire organizations and dispatch philosophies against specific wildfire conditions and resource values, which identifies MEL. The analysis is carried out at the smallest organizational level that is responsible for planning, budgeting, and administering its own fire management plan (NFMAS Reference Material 1992). For the Forest Service this is most often the National Forest. Budget data so generated can be aggregated to generate a national budget request.

NFMAS treats suppression expenditure differently. For each fire fighting resource, in each geographical location a fire intensity level at which this resource is to be dispatched is established (*fig. 2*).

Figure 1
NEMAS included items list.

Figure 2
Default FIL dispatch levels.

The screenshot shows the 'IIAA Interagency Initial Attack Assessment (SAU1)' window. The 'Line Items' tab is active, displaying details for 'Air Tanker 01' with a budget of \$3,100. The 'MRT Defaults' sub-tab is selected, showing the following values:

Parameter	Value
Water Dropping Air Tanker or Helicopter	10
UAC	1600
Break UAC (supplied)	3
Cost Per Mile	1900
UAC Per Release	4
Speed (MPH)	215
Default	4
Total Number of Water Drops	4

At the bottom, there are checkboxes for 'Use Auto-MRT For This Line Item' (checked) and 'Wait for Arrival of ENG or WLT' (unchecked). A toolbar at the bottom includes buttons for 'Clear', 'Save', 'Search', 'Delete', 'First', 'Prev', 'Next', 'Last', 'Edit', and 'Print'.

An important consequence of treating suppression in this way is that suppression expenditure cannot be fixed independent of presuppression expenditure. As the number of resources on the included items list is changed this will have a direct effect on suppression expenditure. This means that partial sensitivity analysis cannot be correctly carried out on presuppression levels, as suppression expenditure cannot be kept constant.

Finally, how is the mix of presuppression resources treated? The importance of optimizing the mix is recognized in NFMAS literature, "[The objective of NFMAS is] identifying the most efficient (lowest C+NVC) program budget, and the mix of program components that goes with that budget" (NFMAS Material 1992). Does the NFMAS architecture allow for the identification of the efficient mix of resources? The problem with suppression not staying constant as presuppression varies also applies to the case of varying the presuppression mix. This leads to an identification problem that will prevent the efficient mix from being found. The inability of NFMAS to assure technical efficiency in presuppression organizations means further identification problems in trying to find optimal levels of presuppression and suppression. For example, if an increase in presuppression expenditure results in a decline in C+NVC, there is no way of knowing whether this is a result of the increment of presuppression expenditure, changes in technical efficiency, or changes in suppression activities.

An extreme example of technical inefficiency is given by the removal of the NVC function from NFMAS runs. Because this often leaves optimal presuppression little changed is offered as evidence of NFMAS's insensitivity to resource values (Bell and others 1995). This observation illustrates both the issue of technical efficiency and misunderstandings about its importance to the NFMAS process. If the NVC function is removed from the analysis because neither presuppression nor suppression expenditure can reduce the damages of wildfire, then the optimal level of both is zero. Any solution that has positive values of presuppression and suppression is technically inefficient, as C+NVC can be reduced (in this case to zero) without increasing expenditure on presuppression or suppression. This misconception seems to indicate that although NFMAS users are told to consider presuppression mix, it is perhaps not being given the weight it should.

Thus, NFMAS is not able to correctly perform a partial sensitivity analysis. Because sensitivity analysis is central to identifying efficient solutions, any C+NVC curve generated will be on, or more likely above, the true C+NVC curve. There is also reason to believe that the levels of MEL generated by NFMAS will be systematically higher than those of the true C+NVC curves.

The reason for this stems from the deterministic nature of NFMAS. Previously, we pointed out that suppression levels depended both on the dispatch philosophy and the presuppression level. While an aggressive dispatch philosophy is not the sole determinant of suppression level, it will tend, all other

things being equal, to increase suppression expenditure. Under certain production conditions this will increase the marginal productivity of presuppression resources, thereby increasing the optimal level of presuppression. The required production conditions are that the cross partial of the NVC function with respect to presuppression and suppression is positive:

$$\delta^2 \text{NVC} / \delta S \delta P > 0$$

Nicholson (1995) says that while this is the most prevalent case, this is not necessarily always true. Truet (1984) goes further and gives examples of when production functions might not have a positive cross partial. He states that a negative cross partial is nearly always found between two inputs that are very close substitutes. The example of male and female waiters in the production of meals at a restaurant is given. This close substitutability would not seem to be the case in the wildfire problem. Consider the case of an air tanker. If presuppression resources are not used to buy the air tanker, then it can't be used as a suppression resource. The requirement of some expenditure on one of the inputs in order for the other one to contribute to the production process, implies a degree of complementarity, and therefore a positive cross partial, over the range of output examined.

An NFMAS user who uses an aggressive dispatch philosophy will likely generate higher levels of MEL. Therefore, NFMAS generated C+NVC curves will likely be above the true C+NVC curve, and their minimum will occur at higher levels of presuppression expenditure (budget).

Improvements to the NFMAS Process

If the current NFMAS architecture is to be retained, then the most important improvements that could be made are those that would allow partial sensitivity analysis to be correctly carried out. Of these, the most fundamental is that NFMAS has the capacity to vary one input while holding all others constant. The included items list allows presuppression to be held constant, so no changes are required in the way that NFMAS fixes presuppression. The way that the dispatch philosophy is currently used does not allow suppression to be fixed. However, the use of a dispatch philosophy does have some operational realism, so there may be some benefit to retaining elements of it. One solution would be to use the dispatch philosophy to rank resources in order of importance, and use this ranking in conjunction with a suppression budget cap to determine what resources should be used given a particular budget.

Ensuring technical efficiency for each presuppression organization is problematic. For example, each change in presuppression expenditure may result in significant changes to the efficient mix of resources. The fact that the majority of a presuppression organization's budget may consist of a few high cost items (For example air resources.) makes this problem worse. Consider the example of two presuppression organizations with a modest increment in budget between them. The organization with the smaller budget may have been just unable to afford an air tanker, and so would have to rely more heavily on less productive ground resources. The organization with the higher budget would be able to afford the air tanker and would therefore use less ground resources. If changes were made in the way that NFMAS deals with suppression, then the main problem NFMAS has in ensuring technical efficiency is a practical one. The number of runs that would have to be made in order to ensure the technical efficiency of just one presuppression organization are daunting. Considering the numerous runs that are required to identify MEL, the number becomes prohibitive. Thus, even if the flaws in NFMAS's sensitivity analysis are addressed, practical problems remain that would prevent MEL from being reliably identified. If the current NFAMS architecture is inappropriate, then what would be a better approach?

Considering the problems with the current NFMAS process and issues that have risen in importance since its development as well as vastly improved computer and programming technology, an optimization approach should be considered. For example, an optimization approach could address the problems that NFMAS has with sensitivity analysis, and with optimizing the mix, as this would be carried out by the program. Ecosystem considerations are becoming an increasingly important part of the fire management problem. These ecosystem constraints do not fit easily into current C+NVC models. We suggest that the fire management problem will increasingly become a constrained optimization problem. As such the way that any program manages these constraints will be as important as the way in which the objective function is optimized. Optimization is well suited to this sort of process and would provide valuable information on the costs of these constraints.

FIREPRO

FIREPRO is a computerized fire management budget planning and programming system developed and used by the National Park Service (NPS 1997). FIREPRO has very different goals and approaches to the fire management problem. This is partly because of the different objectives of the NPS. The NPS is charged with land stewardship and public enjoyment of lands rather than resource utilization (NPS 1997). Rather than having a goal of optimizing an objective function, such as NFMAS, FIREPRO was designed to implement nine program performance targets. These targets address such issues as initial attack success rate; hazard fuels reduction projects; and fire effects monitoring. FIREPRO was designed to implement these targets at least cost. To thoroughly define a least cost solution these items must be generated: presuppression level, suppression level, and the mix of presuppression activities.

FIREPRO focuses on generating staffing levels, and as such, it does not address all components of a presuppression organization, such as capital equipment. It is impossible to calculate the efficient level of staffing for a fire organization without considering all elements of that organization. This is because the utilization of one resource will have an affect on the productivity of another, and thus its efficient level. Similarly, FIREPRO does not generate a complete suppression budget, which needs to be done even if the user is not directly concerned with suppression levels. Finally an efficient mix of presuppression resources cannot be arrived at for the same reasons.

Unlike NFMAS, FIREPRO does not have a simulation component but applies a rules base approach to analyze a park's workload and program complexity to assign a fire management budget. Ninety-six matrices are used to perform the actual analysis.

Another major difference between the two programs is the role of the user. Unlike NFMAS, FIREPRO is operated centrally with the parks providing data, but not conducting the analysis. The FIREPRO analysis falls into four phases, with the user making changes to the raw output (output generated by the matrices) in the last three phases. These changes are made in response to unique local conditions, or because the user feels that the unmodified output will not help parks reach their performance targets. An advantage of having fixed performance targets is that they provide verifiable grounds for budget changes. However, this is predicated on the performance targets themselves being appropriate.

FIREPRO could generate a complete fire organization, but because it lacks a simulation component, it could not compare alternative organizations. For the sake of illustration, the FIREPRO process can be considered to have two parts. The first part is the attainment of the program performance targets. The success of this part of the FIREPRO is verifiable at the end of a given fire season. The second part of the FIREPRO process is ensuring that these targets are achieved at

least cost, which FIREPRO cannot do. The problems with the FIREPRO process stem from the scope of the analysis being too narrow and that alternative organizations cannot be compared. Thus, changes to the current FIREPRO framework should concentrate on expanding the elements of a fire organization considered by FIREPRO and including a capability to compare different organizations.

Discussion

NFMAS and FIREPRO embody different approaches to the fire management problem, reflecting contrasting agency missions. Both programs were developed from the ground up and represent real progress in applying economic principles to the fire management problem. However, if some of the areas for improvement in this paper were addressed, the two processes might be more similar. For example, one of the main problems with the FIREPRO process is that its scope is too narrow. If FIREPRO were to consider all elements of presuppression and suppression, along with a simulation component, then the two processes would be more similar. The optimization approach suggested for NFMAS would be particularly useful to the NPS with its many ecological constraints. It would be a more productive approach to design a program around a generic principle, such as constrained optimization, rather than allow the specific agency requirements to drive the establishment of the core process. With this central principle in place, its application could be agency specific.

Misconceptions about the C+NVC model are likely a result of the shortcomings of NFMAS and FIREPRO. Recognizing and addressing inconsistencies with basic economic theory often takes years to resolve; for example, consider the amount of time the 10:00 a.m. policy was considered to be economically efficient. Misconceptions regarding the original work of Sparhawk (1925) and more contemporary related models have only recently been revealed. Assimilating such change and transferring the change into modern technology and planning models is typically a lengthy path.

C+NVC is a strategic level theoretical model that illustrates the relationships between the fire management inputs and outputs. It does not however address many of the practical problems that arise when trying to operationalize the problem. For example, the issue of technical efficiency (the efficient mix) is not addressed explicitly but is of paramount importance to any operational model. The C+NVC model provides a theoretic framework that any tactical model should adhere to; however, it does not directly address many operational issues, such as ensuring an efficient mix that is necessary for operationally viable implementations. A thorough understanding of the role of the C+NVC model will help in improving current models and developing others.

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Using Control Theory to Model the Long-term Economic Effects of Wildfire¹

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Abstract

Wildland fire management strategies often have long-term economic and ecological impacts, as evidenced by the increase in fire danger resulting from the total suppression policy of the last several decades. In the long run, the choice of an optimal wildland fire management strategy depends upon the cumulative effects of fire management factors as well as the interaction between them. A theoretical extension to the cost plus net value change (C+NVC) model is developed by using the principles of control theory. It explores the long-term relationships among the factors of production and the choice of optimal management strategies given that fire management actions have consequences in the future.

Introduction

The cost plus net value change (C+NVC) framework has been the most widely used economic fire management tool since its inception in 1916 (Headly). Although the model has evolved to account for changing management philosophy (Gorte and Gorte 1979, Pyne 1996), further adaptations will enable managers to meet the objectives of ecosystem management. Wildfire managers are broadening their focus from individual fires and annual budgeting concerns to include ecosystem-wide objectives and long-term effects. Such objectives include long-term cost efficiency, sustainability of fire programming, and the consideration of ecological effects (Williams and others 1993). These objectives are important aspects of ecosystem management and fire planning, yet are not adequately addressed by existing models.

The C+NVC model minimizes the sum of fire management expenditures plus the net change in resource value for damaging wildfires. Total costs include annual expenditures on suppression and presuppression. Presuppression, or program level, is a combination of fire management activities (prevention, detection, and fuels management) that constitute the fire management mix (Mills and Bratten 1988). Once the program level has been defined, the optimal combination of presuppression activities is then determined (González-Cabán and others 1986).

Research to improve various components of the C+NVC model has included efforts to reduce program cost or to improve the efficiency of the fire management mix derived from the least cost program level. For example, Bellinger and others (1983) analyzed the cost effectiveness of resulting program levels and determined that the program cost was appropriate, yet efficiency could be improved by reallocating management mix activities. Similarly, González-Cabán and others (1986) used the C+NVC framework to demonstrate that an efficient management mix can be determined, given the optimum program level. Mills and Bratten (1982) developed the Forest Economics Evaluation System (FEES) to address cost effectiveness and efficiency of C+NVC based programs. Upon testing it (1988) they determined that the total program cost was almost solely a function of presuppression. Finally, Hesselin and others (1998) developed a theoretical extension to the C+NVC using catastrophe theory. They modeled the production function for wildfire behavior and subsequently related environmental and ecological effects to economic outcomes of wildland fire management (Hesselin and others 1999). These research efforts, however, do not consider the long run.

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Fire management activities often have profound long-term effects on the ecology of a region, and over time, affect how the landscape responds to wildfire (Wade and Lundsford 1990, Weber and Taylor 1992). Similarly, the effects of current fire management investments, such as fuels reduction, will likely be manifested in the future through reduced hazard of catastrophic fire and resultant ecological, physical, and financial damage. The C+NVC model, as it is currently used, does not embody the theoretical association between fire management programs and ecological effects elicited by those programs, and therefore, does not address long-term ecosystem management objectives. Furthermore, theoretical extensions of the model to address long-term sustainability of fire management programs-combinations of presuppression and suppression-have not been developed, thereby ignoring potentially important economic ramifications of various fire management activities.

To better enable managers to address long-term economic objectives, we develop a theoretical extension to the C+NVC model by using control theory. Our objectives are to explore the long-term economic relationships among fire management activities and physical and financial damage, and to investigate the applicability of control theory to formulate a long-term optimization model. Our analysis is an extension of the C+NVC cusp model (Hesseln and others 1998, Hesseln and others 1999) that embodies environmental and ecological effects of fire behavior. We begin first with a review of the C+NVC model and then discuss the principles of control theory in the context of fire management modeling. Finally, we conclude with a discussion of long-term fire management planning.

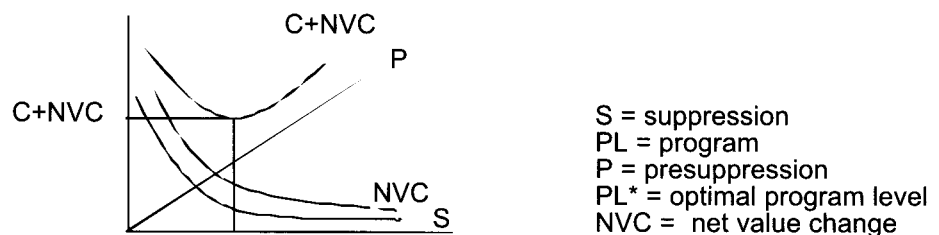
Evolution of the C+NVC Model

The C+NVC model was developed to minimize the sum of fire management expenditures plus the net change in resource value resulting from wildfire. The relationship between fire management expenditures and net value change is specified by equation [1]:

$$C + NVC = W^S S + W^P P + NVC(S, P) \quad [1]$$

in which cost C is the sum of suppression and presuppression expenditures S and P evaluated at their prices W^S and W^P . The net change in resource value NVC is a function of management activities S and P (*fig. 1*).

Figure 1
Cost plus net value change (NVC).



Presuppression expenditures in dollars, is represented along the x-axis (*fig. 1*). It is assumed presuppression is inversely related to suppression and net value change; thus, as presuppression expenditures increase, suppression expenditures and NVC decrease. When the curves are added vertically, the resulting bowl-shaped curve represents the total cost plus net value change (*fig. 1*). The optimal level of presuppression corresponds with the minimum of the C+NVC curve. The optimal level of presuppression is also known as program level or preparedness and represents the annual programming budget for the USDA Forest Service. For example, the National Fire Management Analysis System (NFMAS) uses C+NVC as an economic basis to estimate the expected annual cost

of fire management (Brandel 1988) where the resulting program level is calculated by using historical program levels and net value change figures. However, past fire management programs are not directly associated with future programming needs or ecological effects in subsequent years (USDA 1993).

Although the model has undergone several changes in response to changing management philosophy, it fails to incorporate significant factors. First, the model is not based on fire behavior, which is often erratic and seemingly unpredictable. Second, there is no consideration of environmental factors that can widely influence fire behavior and subsequent, physical, ecological and financial damage. Furthermore, although the relationships among suppression, presuppression, and net value change are somewhat intuitive, such relationships have never been tested. Finally, the model is static and does not consider the long-term relationships between fire management factors and ecological outcomes.

In an effort to address these problems, Hesseln and others (1998) modeled a production function for fireline intensity by using a cubic equation. Equation [2] represents fireline intensity I as a function of a and b which are linear combinations of ecological and environmental factors, windspeed, initial 1-hour fuel moisture, and fuel loading, expressed by equations [3] and [4]:

$$V'(I) = I^3 + bI + a = 0 \quad [2]$$

$$a = a_0 + a_1(\text{windspeed}) + a_2(\text{fuel-loading}) + a_3(\text{fuel-moisture}) \quad [3]$$

$$b = b_0 + b_1(\text{windspeed}) + b_2(\text{fuel-loading}) + b_3(\text{fuel-moisture}) \quad [4]$$

Physical and financial damage are then directly related to fireline intensity through equation [5]:

$$NVC = f(I) \quad [5]$$

which is substituted into the C+NVC equation [1] to produce equation [6]:

$$C + NVC = W^S S + W^P P + NVC(I(S, P), A(S, P), R) \quad [6]$$

Cost plus net value change is thus dependent upon fire behavior through fireline intensity (I), which is a function of environmental and ecological variables (a , b). This expression expands the range of expected C+NVC values, given the volatility of fire behavior and environmental factors. To solve for the optimal levels of suppression and presuppression, we differentiate equation [6] with respect to S and P .

$$\frac{\partial(C + NVC)}{\partial S} = W^S + \frac{\partial NVC}{\partial I} \cdot \frac{\partial I}{\partial S} + \frac{\partial NVC}{\partial A} \cdot \frac{\partial A}{\partial S} = 0 \quad [7]$$

$$\frac{\partial(C + NVC)}{\partial P} = W^P + \frac{\partial NVC}{\partial I} \cdot \frac{\partial I}{\partial P} + \frac{\partial NVC}{\partial A} \cdot \frac{\partial A}{\partial P} = 0 \quad [8]$$

Equations [7] and [8] state that suppression and presuppression will be optimal where the marginal cost of a fire management activity defined by its price is equal to the marginal benefit resulting from such activity. Furthermore, equations [7] and [8] indicate the marginal effectiveness of S and P on the reduction in damage through both fire control via fireline intensity and containment via area burned (Hesseln and others 1998).

Although the cubic model is based on fire management behavior and environmental parameters, it does not evaluate long-term effectiveness of fire management activities. The C+NVC model expressed by equation [6] does not reflect the cumulative nature of management actions and ecosystem response

over time. Cost in one period is currently directly related to management expenditure in that same period and resulting net value change or expected damage. Furthermore, it ignores the complex relationships among suppression, presuppression, and net value change. To effectively evaluate fire management programs, the model could be specified over the long term to capture the investment return relationships between fire management activities and long-term effects. Control theory may provide a method by which to evaluate long-term fire management activities.

Principles of Control Theory

Control theory is used to optimize problems where decisions are related through time. Rather than optimizing a variable in a single time period, we recognize that decisions are dynamic in that the choice of a decision variable in one time period will affect future choices of that decision variable. Similarly, the decision variable will also affect ecological and economic outcomes throughout the planning period, further complicating the choice of optimal management variables. Therefore, to optimize decision making, we seek to determine the optimal time path of decision variables over a specified period (Silberberg 1990). There is ample evidence that fire management is dynamic and could be enhanced if considered in this context.

The relationship between fire management activities, particularly prescribed fire, and net value change has become evident as the effects of past fire management programs manifest themselves in a changing ecosystem (Arno and Brown 1991). For example, a past policy of complete fire exclusion without prescribed burning led to ecosystem changes resulting in increased costs and losses from a higher incidence of fire and disease. In ecosystems where the natural fire frequency is relatively high, the detrimental effects of fire exclusion are just now being realized (Mutch 1994). The total suppression policy intended to eliminate fire and reduce damage has, in some ecosystems, exchanged present damage for future damage. Omi and Kalabokidis (1991) studied the effects of fire on intensively managed lands by comparing forests in Yellowstone National Park with adjacent forests after the large conflagration of 1988. They concluded that intensive management practices such as the removal of standing and fallen dead material, appeared to reduce the severity of fire damage. Birk and Bridges (1989) conducted a long term experiment on the effects of fuels management and concluded that under a prescribed burning regime, wildfires would be less intense, have lower rates of spread, and therefore could be more easily confined to smaller areas. Given the long-term relationships between fire management actions and ecological and economic outcomes, it may be possible to employ the principles of control theory to enhance decision making.

Control theory is based on four basic assumptions (Lambert 1985). First, there is a relationship between the decision variable, known as the control variable, and future changes in the condition of a resource, known as the state variable. In fire management this is the relationship between fire management activities S and P and their effects on NVC. Second, management decisions are related through time. For example, a decision today to invest in prescribed burning will affect future prescribed burning expenditures depending on the ecological effects, such as hazard reduction and ecosystem restoration--thus making management decisions dynamic. Third, the state of a resource depends on the initial condition of the resource as well as the effect the control variables may have on that resource over time. For wildland fire management, this is particularly important in that areas with relatively high fuel loading and fire hazard may require more management effort to reduce fire hazard and to restore natural conditions. Finally, it can be assumed that the natural system will achieve a steady state. If managers seek to achieve natural mean fire intervals (MFI) of relatively high fire frequencies and low

fireline intensities, the targeted MFI will help to determine the length of time over which to evaluate fire management actions.

The general form of the dynamic problem is specified as follows. The state variable NVC defines the state of the resource that is affected by control variables suppression and presuppression. The model, in its general form, is expressed by the objective function [9] and the state equation [10]:

$$\text{Max}_{S,P} \quad \int_{t_0}^{t_1} -f(S(t), P(t), NVC(t), t) e^{-it} dt \quad [9]$$

$$\text{S.T.} \quad NVC' = g(S(t), NVC(t), t) \quad [10]$$

$$NVC(0) = NVC_0, NVC(T) = NVC_T$$

To minimize the sum of costs plus NVC, subject to both changes in NVC resulting from management activities, and a targeted mean fire interval, we integrate equation [9] over a specified planning period. The solution will yield optimal functions (paths) for management variables S and P, which will generate an optimal path for the state variable NVC. Management will depend on the path of optimal decisions over a specified planning horizon and the net present value of a stream of decisions rather than the sum of decisions made independently of each other over a series of years. Therefore, S and P indicate paths of decision variables made over the planning horizon rather than annual levels of decision variables (Silberberg 1990). To minimize C+NVC, we maximize the negative of equation [9].

To solve the model we formulate a Lagrangean equation [11] using 1 to represent the marginal value of NVC:

$$L = \int_{t_0}^{t_1} \{-f(S, P, NVC, t) + \lambda(t)[NVC' - g(S, P, NVC, t)]\} e^{-it} dt \quad [11]$$

and minimize the sum of fire management expenditures plus net value change over the planning period subject to the state equation. The term 1 represents the marginal value of NVC known as the costate variable. Because equation [11] is expressed partially by differential equations, we break the problem into parts and integrate over two distinct periods defined by the endpoint condition T:

$$L = \int_0^T [-f(S, P, NVC, t) + \lambda g(S, P, NVC, t) + \lambda' NVC] e^{-it} dt \\ + [\lambda(T) NVC(T) e^{-iT} - \lambda(0) NVC(0)] \quad [12]$$

Rewriting the first two terms in equation [12] using the Hamiltonian equation (Lambert 1985) to separate terms through time yields equation [13], which can be solved using the Hamiltonian conditions:

$$L = \int_0^T -[H(\lambda, S, P, NVC, t) + \lambda' NVC] e^{-it} dt + [\lambda(T) NVC(T) e^{-iT} \\ - \lambda(0) NVC(0)] \quad [13]$$

The first-order conditions for maximization are as follows:

$$0 = \frac{\partial H}{\partial S}, \quad 0 = \frac{\partial H}{\partial P} \quad [14]$$

$$-\lambda' = \frac{\partial H}{\partial NVC} \quad [15]$$

More specifically, equation [14] represents the optimality conditions, and equation [15] is the differential equation of the costate variable. The final condition [16] is the differential equation for the state variable and ensures that the constraint expressed by the state equation [10] is true.

$$NVC' = -\frac{\partial H}{\partial \lambda} \quad [16]$$

After the fire management problem is specified in terms of the relationships between S, P, and NVC, the Hamiltonian conditions can be used to solve for the optimal paths of the control and state variables to generate the optimal program levels (Lambert 1985). Rather than generating annual estimates for fire management activities, the solution to the control problem will provide the optimal paths for fire management activities over a specified rotation.

Discussion

Theoretical frameworks linking short-term activities to long-term effects and objectives are becoming more important as public land management agencies increasingly embrace the tenets of ecosystem management. This paper develops a general extension to the C+NVC methodology to provide a theoretical foundation that directly addresses those tenets. The distinction between annual and long-term fire programming demonstrates that long run cost minimization and efficiency is ultimately dependent upon the damage caused by wildfire as represented by NVC' and the inter-temporal relationships among fire management activities and economic and ecological outcomes. Furthermore, the control theory model embodies the relationship between fire management activities and their resultant effects on the ecosystem over time. In this way, long-term costs and ecological considerations are embedded in the C+NVC model.

The control theory model may also be used to compare the marginal and relative effectiveness of P and S in the long run. A direct relationship between presuppression expenditures and ecological and economic outcomes may lead to enhanced fire management efficiency and reallocation of expenditures away from suppression. To minimize the cost of fire management applications, current fire management policies could be reviewed with stronger emphasis on the relationship between presuppression activities and long-term ecological impacts while more fully incorporating the estimated cost of suppression. For example, budgeting and planning systems such as the USDA Forest Service's NFMAS use the C+NVC framework to solve for the least cost program level (presuppression). The minimum program cost, however, does not accurately reflect the expected cost of fire management for a given time period because the resulting budget does not include scheduled suppression expenditures beyond initial attack. For large fires requiring more suppression than initial attack, funding comes from an unlimited emergency source (United States Congress 1989). The unlimited suppression funding has the effect of increasing total fire management cost for the season beyond the optimal level. A more comprehensive approach will more directly link annual practices with long-term ecological effects and include the cost of suppression funded by the emergency budget. Such an approach will also evaluate the trade-offs between current spending on presuppression versus future spending on suppression.

Application of the control theory approach will require formal specification of the relationships between S, P, and NVC--in particular, the relationship between suppression and presuppression over time. Furthermore, it may be desirable to identify and include a variety of control variables for several fire management activities irrespective of general expenditure category. Finally, in choosing a control variable, it may be beneficial to use a measure other than the traditional net value change. If ecological variables better describe the state or

value of a resource, and can be measured, tracking the change in the state variable over time could provide better links between fire management objectives and resulting changes in the ecosystem.

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A Dynamic Programming Approach to Determining Optimal Forest Wildfire Initial Attack Responses¹

Marc R. Wiitala²

Abstract

A mathematical optimization model, based on the operations research technique of deterministic dynamic programming, is offered as a method to search quickly through available options to find the economically efficient set of initial attack resources to suppress a wildfire. Considerations in selecting initial attack resources for an efficient initial response include cost of transportation and use, line construction productivity, response times, resource complementarities, size of fire upon discovery, rate of fire spread, fire damage, mop-up cost, and fire benefits. The dispatch optimization model has several applications, such as developing pre planned and real-time dispatches and evaluating the economic efficiency of new initial attack technologies.

For many years a quick and strong initial response was deemed paramount to successfully suppressing a forest fire. To achieve this objective, the criterion of closest forces was used to select the suppression resources deemed necessary for the initial attack effort. Much of the early supporting research focused on automating the process of finding closest forces (Mees 1978). Little attention was given to the cost of the initial attack response and the economic trade-offs that could be made with costs and resources losses associated with fire size.

Over the past two decades the cost of maintaining an initial attack organization of sufficient size to make quick and strong initial attack responses increased steadily and significantly. Facing ever tightening budgets, dispatchers became more interested in balancing the cost of the initial suppression response against the benefit of reducing fire size. In response, researchers began to explore formal methods to help dispatchers select the most efficient initial attack suppression response. Even before the concern with economic efficiency, Parks (1964) presented an analytic solution for finding the economically optimal suppression effort. When the efficiency issue became more pressing, Parlar and Vickson (1982) revisited Parks' model. They offered an alternative solution using optimization techniques from control theory. Both models focused on the most efficient size and timing of the general suppression effort. Neither model considered the importance to the dispatch decision of differences among individual suppression resources in response times, line building rates, and other significant fire fighting traits. Because these considerations were and remain important aspects of the dispatch decision, neither model became operational.

In subsequent research developments, resource differences important to the dispatch decision were considered. A foray in this area was initiated by Wiitala (1986) in pioneering the use of dynamic programming to find cost-effective dispatches. A similar approach was taken by Kourtz (1989) for dispatching water bombers and for delivering crews by helicopter. Although Wiitala (1986) attempted to account for all initial attack suppression costs, the dynamic programming algorithms by Kourtz (1989) minimized only transportation cost. Kourtz (1989) did not formally consider resource loss or other types of suppression related costs nor the economics of the strength of the attack.

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In determining an appropriate suppression response, the efficiency-minded dispatcher considers all costs and losses. A balance must be struck between the cost of the suppression effort and those costs and losses associated with fire size. However, finding the cost efficient dispatch is a task made difficult by the availability of numerous initial attack resources dispersed over many locations that exhibit a wide range of characteristics. For each available suppression resource the dispatcher must know its location, transportation cost, line building cost, line construction rate, and response time. Also important are line building interactions between resources and any constraints affecting the intensity and duration of a resource's performance. Even with a modest 30 different resources from which to choose a dispatch, the number of combinations that can feasibly contain a fire can easily range into the millions. With so many choices, identifying the most efficient combination to dispatch to a fire is nearly impossible without assistance of computers and operations research techniques.

This paper presents an operations research technique that can help the efficiency-minded dispatcher quickly identify an appropriate initial attack response. This objective is accomplished in two steps. The first step sets forth a general mathematical formulation of the wildfire dispatch optimization problem. The second step reformulates the general mathematical optimization problem to permit using the technique of deterministic dynamic programming to achieve an economically efficient dispatch.

Model Formulation

With many resources available to respond to a fire, the number of possible dispatches may be very large. Every dispatch will have its own fireline building trajectory, containment time, and cost profile. This profile will depend on the types, arrival times, and production rates of dispatched resources. Assuming resources will be sent immediately and will build fireline until the fire is contained, the cost of containment, J , can be formally stated as:

$$J = \sum_{i \in X} x_i (C0_i + C1_i (t - b_i)) + C2(a(t)) + C4(t) \quad [1]$$

in which:

X = the set of initial attack units available to respond to a fire,

x_i = a binary variable (0,1), where a 1 indicates the i^{th} resource from the set, X , of available initial attack resources is included in the dispatch,

t = the length of time the fire has been burning,

b_i = time from fire initiation at which the i^{th} suppression resource begins line building,

$a(t)$ = a function relating area burned to t ,

$C0_i$ = the fixed cost of transporting the i^{th} fire fighting resource to and from the fire,

$C1_i$ = the cost per time unit of using the i^{th} suppression resource at the fire,

$C2$ = resource loss per unit of burned area,

$C3$ = mop-up costs per unit of burned area,

$C4$ = the cost per unit of time of other activities not directly related to fire line construction.

For the case of continuous line building resources, the mathematical problem of finding the most efficient dispatch and containment time, t , to a wildfire is defined as:

$$\text{minimize } J = \sum_{i=1}^n x_i (C0_i + C1_i (t - b_i)) + C2(a(t)) + C3(a(t)) + C4(t) \quad [2]$$

subject to

$$\sum_{i=1}^n x_i L_i (t - b_i) \geq p(t), \quad [3]$$

$$x_i = 0, \text{ for } b_i \geq t, \quad [4]$$

$$x_i = 0 \text{ or } 1, \text{ for } b_i < t, \quad [5]$$

$$t > \min b_i. \quad [6]$$

in which

$p(t)$ = a function describing the relationship between fireline required for containment and burning time, t

L_i = the amount of fire line that can be produced per unit of time by the i^{th} suppression resource.

Constraint (3) requires constructed fireline to exceed fireline needs for containment, while constraint (4) ensures only those suppression units with arrival times less than containment time will be considered for a solution. The binary decision variable, x_i , in constraint (5) requires all suppression resources not violating constraint (4) to be considered for dispatch. Constraint (6) requires containment time to be greater than the earliest resource arrival time.

Depending on the types of resources available for dispatch, several additional constraints and modifications are necessary to address important interrelationships between resources. As an example, for an airtanker's delivery of retardant to contribute to the line building effort, the presence of a ground crew is required either upon arrival of airtankers or shortly afterwards. Also, to make a contribution to the suppression effort, water tenders require the presence of engines.

The mathematical model defined by equations (1) through (6) describes, in the general case, a nonlinear mixed-integer programming problem. The integer nature of the problem arises because many initial attack suppression units are indivisible. Nonlinearity may arise with respect to area related costs and resource loss. These values will increase over time at changing rates related primarily to variable growth in burned area.

Suitably structured, the dispatch problem might be solved by available commercial software packages capable of nonlinear optimization. However, when the dimensions of the problem grow, the optimization methods employed by these packages may not find a solution or may require inordinate amounts of time to find a solution. Neither outcome is acceptable in a dispatch environment.

For some optimization problems the technique of dynamic programming (Bellman 1957) provides a more computationally efficient alternative to other optimization techniques. Fortunately, the objective function stated in equation (2) can be mathematically reformulated to the equivalent:

$$\min_{j \in T} \{ \min_{i \in X} \{ x_i (C0_i + C1_i (t_j - b_i)) \} + C2(a(t_j)) + C3(a(t_j)) + C4(t_j) \} \quad [7]$$

to take advantage of dynamic programming. This reformulation separates the global optimization problem into two procedural steps. In step one dynamic programming is used to find the minimum cost combination of resources from the set of available resources, X , for each containment time t_j in the set T of possible containment times, considering only suppression costs (the expression comprising the interior brackets of equation (7)). This first step is subject to the same constraints stated in equations (3) through (6). Step two identifies the containment time in T that minimizes overall cost. Overall cost includes not only suppression costs, but also time, $C3(t_j)$, and fire size, $C2(a(t_j))$, related costs, and resource loss.

Dynamic Programming Algorithm

Once a fire is detected and location established, initial attack arrival times for all suppression resources can be established. Those resources that can deliver line production to the fire before a specified containment time are viable candidates for the initial response. The time between a unit's arrival and fire containment determines the amount of fire line that can be constructed. This time also determines total cost of line construction that, when added to dispatch and retrieval costs, yields a lump sum cost for using each resource. After stating the containment time objective, determining the most cost effective suppression response is just a matter of finding the combination of resources that will deliver at lowest cost the fireline required for containment.

This reformulation of the dispatch problem allows it to be viewed as a special case of the "distribution of effort" problem (Wagner 1975) with a strong analogy to a discrete capital budgeting problem. The objective for each containment time is to distribute in a least cost way the estimated fireline needs (budget) among the potential sources of fireline-the suppression resources (investments). This fireline allocation problem is easily solved by dynamic programming because the problem can be decomposed into a series of interrelated subproblems, whose easily obtained individual solutions can be composed to solve the larger problem (Nemhauser 1966). In the parlance of dynamic programming, each suppression resource represents a stage, i , in a sequential decision process. At any stage, the state of the system is given by the amount of fire line, 1 , available to be allocated. The dynamic programming recursive formula describing minimum cost at each stage of the solution process is:

$$f_i(1) = \min(x_i C_i + f_{i-1}(1 - x_i L_i)), \quad [8]$$

in which L_i is now defined as the total amount of line the i th unit can contribute to the suppression effort, C_i is the cost of using the i th resource, and x_i takes on the value 0 or 1 to indicate the decision to exclude or include a resource in the dispatch.

A forward recursive algorithm programmed in FORTRAN is used to solve the dynamic programming problem. For each containment time, the algorithm finds the optimum dispatch over a range of fireline needs, not just the one of interest. Several performance enhancing techniques are used to find a solution. The optimum dispatch (recursive solution) for any level of fireline need at any stage is encoded as 0's and 1's in a character array retained in computer memory. This avoids the computational bottleneck of having to use large amounts of external storage typical of many dynamic programming algorithms. The array encoding process also facilitates quick decoding of the solution.

An equally important means of enhancing computational performance is accomplished by deleting from the decision rule character array redundant rules that will be unnecessarily evaluated at each stage of the solution process. Redundant decision rules arise at each state of the solution process when a given rule holds true over a range of a state variable (in this case, the amount of fireline to be supplied by potential resources).

The FORTRAN program also serves to process the initial attack resource data file for the specific data inputs required by the dynamic programming algorithm. Management of data inputs and optimizer outputs is currently handled by a system of linked and compiled spreadsheets. To further facilitate use of the optimization model, efforts are currently underway to embed the dynamic programming algorithm in a windows computer environment.

Table 1—Estimates of fire size and needed fireline for alternative containment times.

Containment time	Fire size	Fireline
hours	hectares	meter
1.5	1.4	483
2.0	2.1	604
2.5	3.1	724
3.5	5.7	966
4.0	6.9	1,086
4.5	8.5	1,207
5.0	10.5	1,328
5.5	12.5	1,448
6.0	14.6	1,569
6.5	17.0	1,690

Model Application

Application of the optimization model is illustrated for a hypothetical fire occurring on the Mt. Hood National Forest near Portland, Oregon. The data for the example is taken from a preplanned dispatch. Before applying the model, the dispatcher must determine fire characteristics for a set of fire management scenarios, prepare a list of information on available initial attack resources, and estimate per acre resource loss and mop-up cost.

Fire Management Scenarios

A fire management scenario is an estimate of fireline needed to contain a fire at some future time. In this example the fire exhibits a forward rate of spread of 1.67 meters per minute in medium logging slash. With additional information on the fire environment, fireline and fire size estimates were made for 13 potential containment times (*table 1*).

Initial Attack Resources

There are a number of initial attack resources available to respond to the fire (*table 2*). The optimization model uses the attributes of these resources to impose various restrictions on resource use and account for interactions between resources in calculating how much fireline a resource can produce for a particular containment time.

The type code is used primarily for purposes of determining how the model calculates a resource's contribution to fireline production (*table 2*). For example, a positive resource type code indicates a continuous fireline building resource, like a crew. A zero code, like that used for airtankers, signifies the production of fireline in discrete increments. The type codes for engines, their crews, and supporting water tenders permit addressing several issues of fireline productivity related to the availability of water. Fireline production of an engine unit is divided between the engine and its crew. This allows accounting for the reduction in total fireline building rate to that of a hand crew if the engine exhausts its water supply before fire containment. The water tender code tells the model to compute a tender's potential contribution to fireline based on the restoration of fireline production to all engines with the same group code which will exhaust their water supplies before containment.

The group number not only associates a water tender with the engines it will tend, it also forces the dynamic programming optimizer to select resources sequentially within the group. For engines and tenders, this feature ensures a water tender will not be selected without first selecting the engines it tends.

The resource availability variable serves two purposes. A designation of 0 or 1 indicates an initial attack resource is unavailable or available, respectively, for dispatching. If a value of 2 is indicated, this will force the dynamic programming optimizer to include a resource in all dispatches for which it can arrive before the containment time objective. This latter feature allows a dispatcher flexibility to deal

Table 2—Initial attack resources and key attributes.

Description	Type	Group	Availability	Response	Production	Transport	Use
				min	m/hr	\$/trip	\$/hr
Patrol #180	3	2	1	30	10	91.63	26.25
Engine 93 200	3	3	1	40	10	227.43	44.45
Engine 47 1000	3	3	1	60	40	246.65	59.45
Tender 48 2000	4	3	1	90	0	213.85	37.70
Engine 64 200	3	5	1	75	10	301.88	44.45
Engine 24 600	3	5	1	88	40	338.07	59.45
Tender 65 1000	4	5	1	110	0	238.98	37.70
Helitack #16	1	7	1	50	60	1,896.50	135.00
Smokeyjumpers #18	1	8	1	94	101	1,653.33	170.00
BD crew #110	1	9	1	77	60	979.00	175.00
Fire crew #2 10	1	10	1	120	60	1,242.50	175.00
Engine 31 200	3	12	1	130	10	447.70	42.71
Hotshot crew #120	1	14	1	135	200	3,388.00	440.00
Dozer	1	15	1	120	400	299.00	89.20
Airtanker#1.1	0	18	1	55	200	7,200.00	0.00
Airtanker#1.2	0	18	1	95	200	4,000.00	0.00
Airtanker#2.1	0	19	1	65	200	7,200.00	0.00
Airtanker#2.2	0	19	1	105	200	4,000.00	0.00

with issues other than economic efficiency that might influence the initial attack response, for example, when a dozer cannot be used because of steep terrain.

Minimum Cost Suppression Response

The dynamic programming optimization model determines the minimum cost suppression response to provide the needed fireline for containing a fire at a specified future time. For each containment time (*table 1*) this is achieved when the optimization model identifies which of the suppression resources (*table 2*) could reach the fire before a specific containment time objective. It then computes the amount of fireline and cost resulting from the use of each resource.

For example, ten resources can contribute to containment of the fire at 1.5 hours (*table 3*). From these the dynamic programming algorithm selects the minimum cost dispatch to achieve the 483 meters of fireline required at the 1.5 hour containment time. Both the resources available to respond and the minimum cost response for each containment time are then determined (*table 4*).

A dollar amount associated with the minimum cost response for each containment time can be obtained (*table 4*). These values can be plotted to show that the least cost containment time is 4 hours at a cost of \$2,186 (*fig. 1*). The associated response is primarily an engine response including use of the dozer. The two earliest containment times require use of expensive retardant delivery by airtankers because ground resources could not provide sufficient production to meet the containment needs in these short time frames (*table 4*). The costs are nearly seven times that of the most cost effective ground resource response.

Minimizing All Costs and Resource Loss

Although a containment time of 4 hours is the least cost suppression response, this time is not necessarily the most efficient when considering other costs and losses. Because the area of a fire increases at an increasing rate over time, mop-up costs and resource loss can begin to weigh heavily at the greater containment times, depending on their importance on a per hectare basis.

The most efficient suppression response is found by identifying the containment time with the least total cost after adding mop-up costs and resource loss to suppression costs. This is illustrated using the current example, where resource loss and mop-up costs are estimated at \$750 and \$200 per hectare, respectively. The most efficient response is now observed to be that for the 2.5 hour containment time (*fig. 2*).

Table 3-Suppression resources available to respond to a 1.5 hour containment time.

Description	Fireline	Cost
	meters	dollars
Patrol 80 #1	12.1	107.88
Engine 93 200	10.0	256.19
Engine 47 1000	22.1	276.37
Engine 64 200	4.0	312.99
Engine 24 600	2.0	440.05
Helitack #16	46.3	1,397.75
Smokejumpers #18	26.5	1,698.66
BD Crew #110	28.2	1060.67
Airtanker #1.1	201.2	7,200.00
Airtanker #2.1	201.2	7,200.00

Table 4-Least suppression cost dispatches by containment time.

Description	Containment time (hours)											
	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0
Patrol 80 #1	X ¹	X	X	X	X	X	---	X	---	---	X	X
Engine 93 200	X	X	X	X	X	X	X	X	X	X	X	X
Engine 471000	X	X	X	X	X	X	X	X	X	X	X	X
Tender 48 2000	X	X	X	X	X	X	X	X	X	X	X	X
Engine 64 200	---	X	X	---	---	---	X	---	---	---	---	---
Engine 24 600	---	---	X	---	---	---	X	---	---	---	---	---
Tender 65 1000	---	---	---	---	---	---	X	---	---	---	---	---
Helitack #1	X	X	X	---	---	---	---	---	---	---	---	---
Smokejumpers #18	---	---	X	X	---	---	---	---	X	X	X	X
BD crew #110	---	---	X	X	X	---	---	X	---	---	---	---
Fire crew #210		---	---	---	---	---	---	---	---	---	---	---
Engine 31200			---	X	---	X	X	---	---	---	---	---
Hotshot crew #120			---	---	---	---	---	---	---	---	---	---
Dozer			X	X	X	X	X	X	X	X	X	X
Airtanker #1.1	X	X	---	---	---	---	---	---	---	---	---	---
Airtanker #1.2		X	---	---	---	---	---	---	---	---	---	---
Airtanker #2.1	X	---	---	---	---	---	---	---	---	---	---	---
Airtanker #2.2		---	---	---	---	---	---	---	---	---	---	---
Suppression cost (\$)	16,437	13,932	7,131	4,751	3,797	2,186	2,952	3,548	4,168	4,324	4,656	

¹X indicates a resource was selected for dispatch; --- indicates just consideration for dispatch.

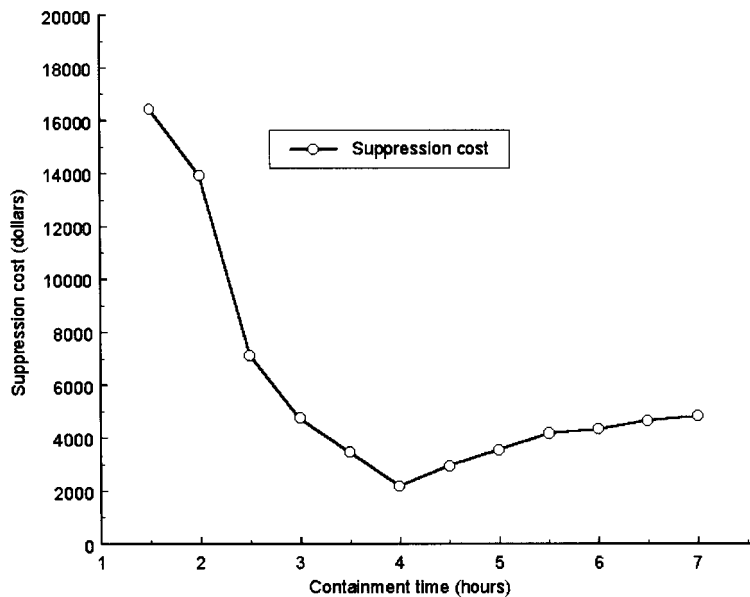
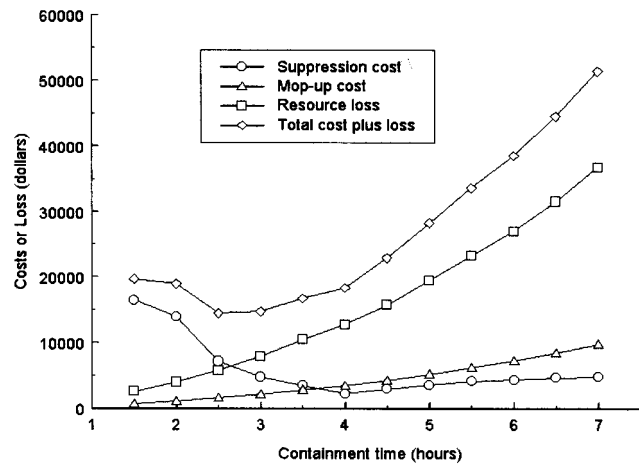
**Figure 1**
Minimum suppression cost by containment time.

Figure 2

Costs and resource loss by containment time.



The most efficient dispatch can be very sensitive to the size of per hectare resource loss and mop-up costs. In this example, higher per hectare loss and cost values would favor the more rapid, expensive, and aggressive attack requiring the use of retardant carrying airtankers. A rapidly spreading fire, all other things equal, also favors an aggressive attack.

Discussion

The dynamic programming model presented in this paper offers a powerful computational tool for finding the most efficient dispatch of available suppression resources to a fire. It also can provide a significant amount of information on economic trade-offs of alternative suppression strategies. This information can be very important to dispatchers when faced with the uncertainty of additional fires and a need to allocate resources between fires.

On the technological side, one virtue of the dynamic programming dispatch optimization model is computational speed. This is particularly important in an environment where timely results are critical. The efficiency of the algorithm is demonstrated by the Mt. Hood National Forest dispatch example where the least cost response of 26 suppression units to 13 containment times took less than 2 seconds to solve on a 200 MHZ micro computer.

For expository purposes, this paper has focused on the use of dynamic programming in a dispatch environment. The algorithm, as contained in the software package, IASELECT (Wiitala 1989), has also been used to address problems in fire planning, ranging from fuels management risk assessment (Wordell 1991) to the evaluation of suppression technologies (Schlobohm 1996).

Opportunities exist for additional research and development to further refine the dynamic programming algorithm presented in this paper. One possibility, internalizing the equations for mop-up costs, resource loss, and fire perimeter growth, would allow the algorithm to search for both the optimal response and containment time.

A more challenging research endeavor would be to formulate a dynamic programming algorithm to solve the continuous time dispatch problem as described in equations (1) through (6). This would ensure the optimum dispatch was not overlooked, which can result when considering a limited number of containment times.

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Application of Wildland Fire Assessments¹

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Abstract

Wildland fire assessment is an attempt to use spatial analysis to highlight priorities for program management. The techniques rely on mapping of risks, hazards, and values, which are aggregated to determine treatment or attack priorities. The process can be applied on a strategic basis in large landscapes across jurisdictional boundaries. Scaled to local situations, the assessment can ordinate fire management zones, providing the basis for tactical planning. The assessment is designed to be iterative, accommodating changes over time and refined by integrating databases from partner agencies and stakeholders. The evolution of the Federal Fire Policy formally recognizes fire as a process essential for ecosystem function and process. As such, management decisions include a wider array of options and an increasing demand for coordinated interagency responses. Wildland fire assessments employ the use of spatial analysis to highlight priorities for program management. Managers are faced with the need to choose appropriate management responses. These decisions are influenced by the need to identify areas in which it is appropriate to use natural ignitions for resource benefit, prioritize the application of prescribed fire, and help to identify priorities for suppression responses and opportunities for intervention or fuel modification.

The shift to ecosystem management dictates planning in different scales and broader scopes. Disturbance regimes will remain a driver in determining the resilience and resistance of ecosystems and an opportunity toward a more holistic approach to land management. The need remains for an ability to conduct large scale assessments that are responsive to interagency needs, adaptable to changing conditions, linked to resource stewardship, and serve as support for strategic and tactical decisions and actions.

Wildland fire assessment is an iterative process that includes the mapping of risks, hazards and values. It ranks and aggregates elements within the landscape to develop sensitivity, goals, and priorities. Ranking can be based on quantifiable and detailed data if it is available. As an ordination process, it also allows for combining databases of different standards, an important consideration for interagency planning and cooperation. Simplicity in the ranking process remains the trademark and the attraction of the process. Given a set of criteria, it relies on planners to develop a relative ranking of high, moderate, or low for each mapping layer. Layers are then aggregated to provide a comprehensive view of existing wildland fire conditions. It can be designed at various scales to provide tiered planning, linking resource needs, community values, and managerial issues.

For assessment purposes risk is defined as the potential for ignition on the basis of human or lightning activity. Occurrence data and fire records are the primary source of input. Hazards are defined as physical or biological features that result in similar fire behavior characteristics. In our experience, we used vegetative data, reduced them to fuel models, and ranked their relative flammability. Values remain the most complex element to map. They are natural or developed features within the landscape that are affected by fire. Effects can be positive or negative that vary by fire intensity, duration, or scale of disturbance. On the smallest scales, it accommodates the most detailed information and provides support for tactical decisions and responses. At the broadest scales, it accommodates a wide range of details and allows planners a strategic perspective with linkages among resource issues and an evaluation of interagency efforts across landscapes.

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Colorado Statewide Assessment

In 1996, an interagency group in Colorado developed a pilot project to conduct a wildland fire assessment on a statewide basis. The project was developed in part to respond to the Federal Wildland Fire Program and Policy Review that directed Federal land management agencies to "jointly establish an accurate, compatible, and accessible database of fire and ecosystem related data" as a basis for fire management and fire reintroduction decisions. The project established a platform for agencies and States to work together to develop plans that address the needs regarding health of the landscape, the needs of affected communities, and a tool to communicate about fire management to the public. Project partners included representatives from the Bureau of Land Management, the National Park Service, Colorado State Forest Service and the USDA Forest Service. The goal of the project was to address these key land management questions:

- Where can we tolerate fire and what can we do to promote the natural role of fire?
- What are the probabilities for catastrophic fire and how can we improve preparedness?
- Are there opportunities to increase efficiency and avoid redundancy?

Project objectives included the development of a process for coordinated planning that addressed these needs:

- Recognize and accommodate the changing needs of the public and land management agencies with regard to wildland fire.
- Promote interagency cooperation, develop coordinated fire management priorities, and identify opportunities for collaborative management.
- Serve as a platform for linking fire programs with other land management functions and resource needs.

In 1996, the effort resulted in the production of the Colorado Statewide Assessment, which is the first attempt to apply assessment techniques to address fire issues at that scale. It demonstrated that agencies can cooperate, and although challenging, various databases can be integrated. Constructed in a geographical information system (GIS) database, it quickly identified key issues. For example, by viewing fire occurrence and fuel models on a large scale, an agency representative made adjustments to relocate resources to increase efficiency. The assessment continues to serve as a communication tool raising awareness for public safety in the urban interface. It served as a vehicle for discussions between land managers, legislators, and representatives of local government. It became a catalyst for identifying priorities for intervention and opportunities for the application of prescribed fire. Techniques learned and refined continue to serve as a basis for other collaborative efforts.

Front Range Assessment

Like many other areas in the western U.S., Colorado continues to experience the impact of urban growth. Expansion of the wildland-urban interface, especially on the Front Range, increased concerns for public safety, and preparedness of fire fighting agencies, and raised the stakes for agency administrators. Concurrent with the statewide effort and employing similar techniques, the Front Range Assessment was produced in 1996. On the heels of damaging wildfires, it grouped vegetation associations by disturbance regimes and used population density to identify areas of highest threat of loss to seek opportunities for

intervention. Known locally as the "Red Zone" map it served most effectively as a communication tool, reaching affected publics through the media and local community meetings. It strengthened efforts with fire prevention partnerships, served as a basis for "defensible space" presentations, and was part of a collaborative effort that resulted in the annual Colorado Wildfire Mitigation Conference. An interagency steering committee was formed to serve as a clearinghouse for efforts, and demonstration areas were sought for watershed restoration activities and the application of prescribed fire.

Winiger Ridge and the Jamestown prescribed burn, in Boulder County, were examples of Federal, State and local agencies involved in joint planning, outreach, and execution of fire mitigation projects. Public confidence was crucial to project success since control lines in some cases were literally on private property boundaries. Working relationships within the fire community have been strengthened, and in 1998 an Incident Management Team from the West Metro Fire Department supported expanded attack on a wildland fire involving mixed jurisdictions.

The South Platte Watershed Restoration Project is another product borne from the Red Zone map. It brings together the Pike National Forest, Colorado State Forest Service, and a variety of interest groups. With matching funds and cost share agreements, the goal is to continue restoration of the watershed after the Buffalo Creek Fire and to seek opportunities for fuel reduction, erosion control, vegetation management, and improvement of aquatic habitat. The Environmental Protection Agency and the Denver Water Board were also drawn as willing partners when heavy sediment loads in highly erosive soils directly impacted water quality and reservoirs in the Denver water supply.

Land Management Planning

Paul Gleason, Fire Ecologist for the Arapaho/ Roosevelt National Forest, applied the principles of assessment techniques in developing the fire element of the Forest Land Plan Revisions. Incorporating current concepts in fire ecology and fire behavior technology, he included crown fire potential, topography and aspect to refine the hazard layer. His aggregation layer delineated the forest into fire management regimes, identifying areas for direct control, perimeter control, and prescriptive control. By using this technique, he has afforded fire managers and agency administrators the opportunity to apply a wide range of management responses on unplanned ignitions. He has also positioned the forest to identify opportunities for the use of prescribed fire for hazard reduction. In addition, Gleason has accommodated fire use to meet a variety of other resource management goals such as forage production and habitat improvement.

Interagency Cooperation and Planning

In efforts to increase efficiency, the Colorado Bureau of Land Management and the Rocky Mountain Region of the USDA Forest Service have sought opportunities to share resources, personnel, and facilities. Under the auspices of pilot projects and confirmed through the "Service First" Initiative, joint organizations and authorities sought efficiency and cost effective delivery of services to the public. The Upper Colorado River Fire Management unit is a result of those efforts. It combines the fire management organizations for the Grand Junction District of Bureau of Land Management with the White River National Forest. Fire managers for one agency oversee programs for the other and resource and personnel are mixed and matched as needed to meet mission needs.

In 1997, the National Office for the BLM issued direction for all State offices to conduct a Level I Analysis. The objective for the analysis was to streamline and articulate preplanned suppression response, identify areas for application of prescribed fire, and strengthen the linkage of fire management to land

management plans. The Grand Junction District complied with that direction. Coincidentally, the White River National Forest was gearing up for revisions in its land management plan and attempting to position itself to expand its prescribed fire program. It became obvious that a common planning effort and planning criteria were in order, and the BLM process was adopted. Under the leadership of Pete Blume, Fire Management Officer, BLM, and Bob Leighty, Fire Staff Officer, USFS, wildland fire assessment techniques were employed as the basis for planning. The BLM Level I analysis served as the basis for building the Values Layer, and we believe it offers the most comprehensive definition we have seen to date. The layer is built by resource specialists, not fire planners. In summary it asks others to categorize the landscape into four classes based on the relative tolerance of fire. They range from:

- Where can you not tolerate any fire. These areas require full control in suppression actions and would not be conducive for prescribed fire.
- Where can you tolerate fire with active suppression. These areas offer a wider range of suppression options and may tolerate some prescribed fire activity aimed at hazardous fuel reduction.
- Where is fire compatible with management goals and activities. These areas have resource management objectives that are enhanced by the use of fire.
- Where is fire an essential part of ecosystem function. These are areas in which administrators can exercise the full range of appropriate management responses and represent local priorities for the reintroduction of fire.

In short, the effort demonstrated the effective use of common planning techniques and decision criteria. The process identifies joint opportunities and priorities, leverages funding, and provides stakeholders with a consistent approach to the landscape.

Other Examples

Wildland fire assessment techniques have been applied in other areas as well. The State of Utah has completed a statewide assessment. Modelled somewhat after the Colorado project, its primary goal was to identify areas of highest risk and to strengthen relationships among State and Federal partners for prevention, intervention, and suppression response. The New York Division of Forestry recently conducted an assessment of Long Island, New York, which has strengthened the cooperation among fire jurisdictions and continues to refine fire planning and suppression responses. The States of Michigan and Wisconsin, along with the Province of Ontario, used the assessment technique to refine and coordinate fire prevention and fire planning efforts. The San Bernardino National Forest remains a front runner in using the assessment technique for tactical planning, identifying priorities for suppression response in an arena of explosive fire behavior that is highly dependent on interagency cooperation. The Forest has shared its expertise to influence linkage among other National Forest and agency partners in the southern California. Chuck Dennis of the Colorado State Forest Service is currently undertaking an initiative termed a "mid-level assessment." It takes a subregional approach and attempts to refine the statewide assessment to improve coordination among local agencies. Similar approaches in Canada and Australia have been developed, although their focus remains on identifying values at risk and the efficiency of suppression responses.

Summary

We believe there are numerous benefits for using wildland fire assessments. Managers can quickly identify areas that may require additional tactical planning or where refinements may be needed. The process compiles a common database for interagency planning and allows for linkages to be made among various levels of planning resolution. Fire managers and administrators can better define sustainability, provide linkages among various resource needs and provide the basis for responses in what are often dynamic and complex situations. By using emerging technology in information systems (GIS and GPS) the process lends itself well to refined analysis of complex landscapes and fire situations. Participants can begin the process with existing data and refine it as new, better, or different data becomes available. It serves as a strong communication tool among fire and resource specialists and managers. More importantly, it provides a forum to interact with affected publics, legislators, and local agencies to surface concerns regarding public safety and the array of fire tools. In large part its simplicity and the ability to reach basic conclusions easily and the visual aspect of its products makes it easy to explain and comprehend.

Current natural resource policy continues to press for changes in approaches to land management. There is an increasing demand to view effects on landscapes and understand linkages between ecosystem functions and processes. Discussions regarding historical range of variability, concepts of lethal versus non-lethal fire, fire return intervals, severity of disturbance, and forest health, all contribute to attempts to identify acres at risk. As a result there are a wide variety of ecological assessments with varying criteria and scales. Habitat conservation, connectivity, levels of sustainability, and watershed restoration continue to press for changes and place demands and needs for differing answers. Off-site effects, downstream impacts, and the management of smoke are but a few examples of the increasing complexity of fire planning. When you factor in social concerns, values of stakeholders, and agency mission and cultures the task can become daunting.

Our continuing concern lies in the fact that many of the assessment efforts are independent of each other. There are no obvious acceptance of protocols, terminology, or common focus with respect to fire. We believe interagency planning and implementation remain crucial to successful management of both wildland and prescribed fire. Varying agency budgets, missions, and scope make it imperative that planning techniques focus on common denominators. Developing analysis techniques that allow for inclusion of differing data standards remain a key to multiple scale, multiple agency planning. We further believe that planning should be a process not a product. As such, adaptive management techniques will continue to refine a common approach. We believe the wildland fire assessment process that we have outlined offers the framework for spatial analysis, linking strategic and tactical plans. It serves as a vehicle for leveraging energy, funding, and linking mission capability to ecological need.

Adaptive management continues to reflect a fundamental change in natural resource management. It incorporates science based management in developing objectives and recognizes the need to reevaluate and revise objectives and techniques. Monitoring is the core for success of adaptive management, the feedback loop to affirm or adjust courses of action. The assessment process establishes a baseline that can be compared to historical range of variability and provides a means to develop relevant information to account for spatial and temporal variation. As planners and managers update assessments, rate and scale of change can be determined. The simplicity of the process allows for the assessment to be done on any kind of mapping system. However, in our experience GIS provides the ideal tool for analysis, simulation, and database

management. The components of the assessment can be modified to include or be overlaid with an activity database. We have seen examples where elements of tactical assessments served as the basis for Wildland Fire Situation Analysis. By incorporating data of fuel modification and mapping of prescribed fire activity, suppression operations were designed to minimize site disturbing activities, minimizing firefighter exposure and effectively using perimeter control techniques.

Future Outlook

There is continued dialog regarding the ongoing evolution of the assessment process. After the statewide assessment was done, we focused our energy to assisting forests and partners in developing local plans. We believe that our next step is to crosswalk broadscale assessments to local planning. We anticipate that aggregated efforts at local levels, will strengthen the large scale effort. We also believe that any improvements at the large scales will influence the quality and priorities for local projects, leading to a more comprehensive and coordinated approach to managing fire on the landscape. Our initial efforts taught us a lot regarding the relevance and sharing of databases. We expect continued evolution in skills and GIS technology to improve our analysis and conclusions. We foresee the infusion of real time and baseline data to drive decisions in complex and dynamic fire situations. Questions remain about how we manage the database, how to disseminate information, how data is formatted, and how we fund and manage the endeavor. The line between structural fire fighting and the management of wildland fire is growing increasingly thin in interface zones. We believe our experience with the assessments process provide us an improved understanding of wildland fire impacts and the relationships among the fire service community. We understand that application and refinement of similar techniques are occurring in structural suppression and urban fire techniques. We anticipate assessment techniques will evolve in the interface that will refine techniques, strategies, tactics, and responses within the fire service community.

In the mean time, we continue to believe that wildland fire assessment techniques have provided a common "picture" of the existing situation. Fire managers have refined and delineated fire management zones on the basis of spatial relationships for further detailed program planning, such as the National Fire Management Analysis System (NFMAS). Most importantly it serves as a means for program coordination and strengthened partnerships. It continues to be an effective tool in reaching affected publics and stakeholders. Its simplicity makes it easy to understand, and consequences of decisions are easily translated. We believe it is a tool that is anchored in an ecological setting and incorporates the human dimensions on the changing landscape. We have also been engaged with others on the application of techniques for other emergency response and disaster preparedness. We look forward to influencing the continued evolution of technique and application of wildland fire assessments.

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The Development and Implementation of Forest Fire Management Decision Support Systems in Ontario, Canada¹

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Abstract

The Ontario Ministry of Natural Resources in Canada has supported forest fire management systems research for more than 30 years. It has worked closely with researchers to develop, field test, and implement many decision support systems that have enhanced forest fire management in Ontario. A comprehensive overview is presented of the work that has been carried out in Ontario and some of the lessons that have been learned.

The Aviation Flood and Fire Management Branch (AFFMB) of the Ontario Ministry of Natural Resources (OMNR) is responsible for forest fire management on publicly owned crown land in the Province of Ontario, Canada. Since the late 1960's, the OMNR and its predecessor, the Ontario Department of Lands and Forests, have worked closely with government and university researchers to develop, test, and implement decision support systems to enhance forest fire management in Ontario. Glenn Doan, Project Officer with the Fire Control Unit of the Ontario Department of Lands and Forests, convinced his colleagues they should explore the possibility of using Operations Research (OR) in Ontario in the 1960's. Martell (1982) and Martell and others (1997) review forest fire management operational research studies including many of those carried out in Ontario. Kourtz (1984) discusses the relationship between centralized control and the use of information technology, and Kourtz (1994) summarizes much of the work he did in Ontario and other jurisdictions.

Forest Fire Management in Ontario

Ontario's Fire Management Program provides fire protection to more than 85 million hectares of crown land. The forest fire protection requirements of resource management clients, other stakeholders, and the public are identified through fire management strategies that specify land management objectives, values at risk, protection requirements, and strategic investment requirements. Those plans include a zoning system and fire management objectives that specify area burned targets and initial attack strategies by area. Wilderness parks and some areas in the far north, for example, receive a different level of protection than the parts of the province that are committed to industrial forestry. The government of Ontario currently spends an annual average of \$85 million (in Canadian dollars) directly on fire management (10-year average costs, adjusted for inflation, 1987-1996).

Ontario's fire program responds to an average of 1,200 to 2,000 fires per year. Fewer than 5 percent of the fires in the intensively protected area escape initial attack to cause significant damage. An average of two to four escaped fires become large fires and require a significant suppression effort each year. Fire management strategies stipulate an annual burned-area target of 80,000 ha in the commercial forest zone, and the average area burned there has remained below this target over the past decade. An average annual burned area of about 200,000

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hectares is the target in the extensively protected area north of the industrial forest. Sixty percent of the fires are caused by people, but lightning causes more than half the fires in the province's West Fire Region. As in other Canadian provinces, lightning caused fires burn a disproportionate amount of the total area burned because they tend to occur in more remote areas and are therefore more difficult and more costly to access and attack.

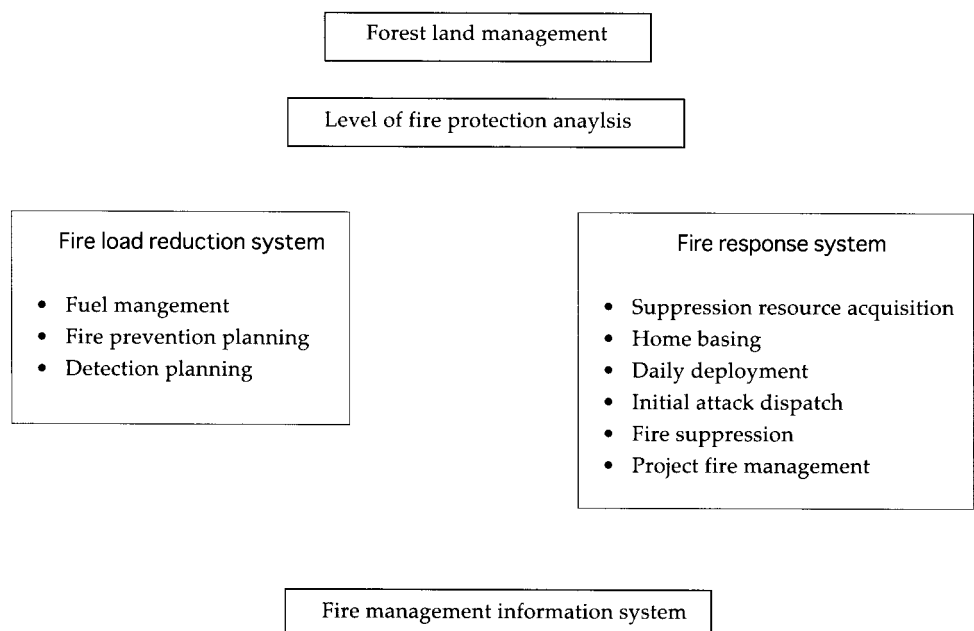
The OMNR operates a large integrated fire prevention, preparedness, detection, response, suppression, and support system. A permanent staff of 220 is augmented seasonally by 640 firefighters and other seasonal staff. The OMNR operates a fire fighting airfleet of nine large amphibious airtankers (CL-215's are presently being converted to CL-415's), five smaller Twin Otter airtankers, and five light helicopters. Fourteen helicopters, fifteen detection aircraft and seven bird-dog aircraft are contracted on a seasonal basis, and additional firefighters and support resources are contracted from the private sector on a short term basis during periods of high fire activity. The fire program is able to draw on additional OMNR staff and resources in the event of a severe fire situation, and it participates in Canada's national resource sharing agreements through the Canadian Interagency Forest Fire Centre.

A Fire Management Systems Framework

Fire management decision support systems in Ontario can be illustrated by the framework presented in *figure 1*. Forest management planning systems use fire management outcomes. Some fire management alternatives are evaluated by using a strategic level of protection planning system that simulates the behavior of the fire management system given specified fire suppression resources and strategies and tactics that govern their use. The fire management system can be divided into two major groups of subsystems: the fire load reduction systems and the fire response systems. The fire load reduction systems can reduce the number and intensity of fires that occur and response systems reduce the cost of containing and limiting the damage that results from fires that do occur. The OMNR has developed a comprehensive Fire Management Information System (FMIS) that provides the crucial infrastructure required to deliver basic weather, fire, and planning information for decision support systems and fire managers. Ontario's FMIS contains components that support both fire load reduction and fire response planning and operations.

Figure 1

A fire management systems framework.



Fire Load Reduction Systems

Fuel Management

With the exception of a small number of projects in blow-down areas and the spring burning of grass along railway corridors and other areas, there is very little fuel management activity in Ontario. However, Ontario does not have the type of fuel build-up problem that is important in the drier climates of the southern United States, parts of the Mediterranean, and Australia. The OMNR did undertake a cooperative research project with Laurentian University to study the feasibility of "green-stripping"-using sowing or planting high-moisture content vegetation types along rights-of-way and other high-hazard or high-value areas to reduce fire ignition potential and spread (Hogenbirk and Sarrazin-Delay 1995).

The OMNR's use of prescribed fire, primarily for silvicultural purposes and to a much lesser extent for wildlife habitat management, waxes and wanes depending upon budget levels, cost recovery policies, and land management objectives. Martell and Fullerton (1988) completed a decision analysis of site preparation strategies, and Martell (1978) developed a prescribed burn fire weather prescription analysis software package (PBWX) that can be used to estimate the likelihood that a specified fire weather prescription might occur on the basis of analyses of historical fire weather data. Kourtz explored the use of the Kourtz and others' (1977) contagion fire spread model for prescribed burn planning purposes. He recently developed an understory prescribed burn expert system for white pine management (UPBX), a large rule-based/neural network expert system that guides managers in their decisions as to the appropriateness of a specific site, and the weather and fuel moisture conditions under which a burn should be carried out. UPBX is currently being field tested by the OMNR (OMNR 1998).

Prevention

Prevention is an important but neglected aspect of fire management, and like most wildland fire management agencies, the OMNR has never been able to quantify the impact of its prevention efforts on fire occurrence. Although Ontario's prevention program managers have frequently expressed serious interest in supporting the development of prevention decision support systems (DSS's), there have been few efforts in this area. Martell attempted to use daily fire occurrence prediction models to relate a reduction in people-caused fire occurrence in a portion of the province to prevention program enhancements. One of Kourtz's fire occurrence prediction models indicated the predicted number of people-caused fires should be reduced by 50 percent when a forest closure is in effect. The OMNR currently uses a system of Woods Modifications Guidelines to advise companies operating in forested areas how operations should be modified on a daily basis in response to the current level of fire hazard (OMNR 1989).

Detection

The OMNR's extensive network of towers has been replaced by aircraft and it also depends upon the public to report fires near populated areas. The shift from very effective but expensive fixed towers to less expensive aircraft that provide intermittent coverage is consistent with Kourtz and O'Regan's (1968) analysis of the cost effectiveness of forest fire detection systems. Given the lack of towers and the use of charter aircraft for detection patrols, there have been no concerted efforts to develop strategic detection planning decision support systems in Ontario, but significant effort has been devoted to tactical detection patrol route planning. Basmadjian (1972) used a decision tree model to decide when to dispatch a single aircraft to look for fires in a single cell. Martell (1975) developed

an adaptive stochastic dynamic detection timing model to determine when to dispatch a detection patrol along a designated route through several cells.

Kourtz (1972) used dynamic programming to specify how to allocate detection patrol effort to sectors and incorporated his model in a simulation model to assess the cost effectiveness of high altitude airborne infrared detection systems in Ontario. He later (Kourtz 1973a) combined a fire occurrence prediction model with a refined version of his dynamic programming model to route patrol aircraft through a subset of a large number of cells to maximize the expected number of fires detected by a patrol of a specified duration dispatched at a designated time. Kourtz (1973b) then modified the infrared patrol system to deal with visual detection patrols. He field tested his model in Ontario during the 1972 fire season and found that it would have routed aircraft closer to undetected fires than the routes the detection planners had used that summer. In the 1980's Kourtz continued to work with a number of agencies to develop and test new detection patrol routing models that stipulated what cells should be visited by patrol aircraft based on the potential loss that might result from fires that might be burning undetected. One approach was to develop a patrol-routing algorithm based on a multiple-salesman traveling salesman algorithm (Kourtz 1991). A modified Lin-Kernighan algorithm and a simulated annealing algorithm were used to solve these large multiple-aircraft routing problems on a daily basis. Martell developed a detection demand index that can be used to specify the relative importance of visiting different cells.

Fire Response Systems

Fire suppression systems have a hierarchical structure, and when decisions support systems are developed for problems in one level of that hierarchy, they must be linked with the levels above and below. For example, when one decides how to home-base airtankers, one must consider the fleet composition level above, which determines how many airtankers are to be home-based, and the daily deployment level below which determines how the available airtankers will be deployed each day.

Fire Suppression Resource Acquisition

Although firefighter hiring can be varied from year to year with little long-term cost implications, the impacts of capital expenditures on aircraft and other infrastructure can last for years or even decades. Martell (1971) developed a simulation model of land-based airtanker operations at Dryden in northwestern Ontario. Cass (1977) developed a mathematical programming model for the management of power pumping units that are transferred from base to base to satisfy demand that varies over the course of a fire season. Doan (1974) developed a comprehensive hierarchical strategic initial attack planning model that embedded a model of the daily allocation of firefighters: transport aircraft and airtankers to initial attack fires in a strategic model designed to evaluate alternative strategies for hiring suppression resources for a season to minimize average annual cost plus loss. Martell and others (1984) developed a comprehensive model of the OMNR's initial attack system in response to a need to up-grade Ontario's aging aircraft fleet in the 1980's. That model, which predicts the consequences of using specified sets of airtankers, transport helicopters, and firefighters to fight historical fires, was used to evaluate initial attack system alternatives and support the OMNR's request to purchase CL-215 airtankers. Boychuk and Martell (1988) developed a strategic planning Markov model of seasonal firefighter needs in Ontario. Tithecott and Lemon (1993) formulated a mathematical programming model that they used to minimize the cost of seasonal helicopters assigned to initial attack bases in Ontario.

Home-Basing

Most forest fire management agencies are now highly centralized organizations that transfer their mobile fire suppression resources from low hazard areas to areas where destructive fires are expected to occur each day. It is essential that those resources be home-based at the start of the fire season to minimize the cost of implementing the daily transfers that take place as the fire season progresses. MacLellan and Martell (1996) developed a mathematical programming model that was used to help evaluate airtanker home-basing strategies in Ontario.

Daily Deployment

Moving down the planning hierarchy, daily suppression resource deployment poses significant challenges for fire managers who must cope with considerable uncertainty concerning fire occurrence and behavior processes that vary over both time and space as they attempt to minimize initial attack response times. Martell (1972) used a decision tree to model decisions concerning the number of initial attack crews required on standby at an initial attack base each day. Booth (1983) developed a stochastic dynamic programming model for determining optimal initial attack crew management strategies over a 3-day planning horizon. Vesprini and Brady (1974) developed a linear programming model that can be used to determine how to deploy fire suppression resources to minimize the cost of satisfying the expected daily demand for fire line in a region. Bookbinder and Martell (1979) modelled the use of helicopters to transport initial attack crews to fires as a queueing system and embedded their model in a dynamic programming model that could be used to evaluate daily helicopter deployment strategies. Two members of the OMNR staff developed a spreadsheet forecasting model that is used to help evaluate manpower planning strategies in anticipation of fire flaps.

Airtanker initial attack systems can be modelled as queueing systems with airtankers as servers and fires as customers. Martell and Tithecott (1991) developed and field tested an $M(t) / M / S$ queueing system model of airtanker operations in the OMNR's northwestern region. The managers that participated in the field test found the model to be interesting but indicated it would not be of any practical use to them unless it was enhanced to account for interaction between bases—that is, an aircraft from any base can be dispatched to any fire in the region within its strike range. Islam (1998) subsequently formulated the airtanker problem with multiple interacting bases and constraints on initial attack dispatch radius as a time dependent $M(t)/E_k / S$ extension of Larson's (Larson and Odoni 1981) hypercube queueing model, and we hope to field test his model during the 1999 fire season. Islam and Martell (1998) investigated how the optimal maximum initial attack strike range varies with daily projected fire load.

Initial Attack Dispatch

Initial attack dispatchers must consider many tangible and intangible factors when they balance the current demand for fire suppression resources with highly uncertain potential future demands. Kourtz (1994) developed an expert system to suggest how water bombers, firefighters, and helicopters should be dispatched to new fires. Expert rules that reflect the agency's policy are used to train a hierarchical set of neural networks that predict the ideal maximum response times and numbers of firefighters and airtankers required at a specific fire, irrespective of the current availability of those resources. A more complex version of that dispatch system uses a dynamic programming algorithm to identify how the available suppression resources can be used to modify the ideal dispatch strategy. Kourtz has also formulated the initial attack expert system problem as a sparse distributed memory problem. The performance of this pattern-based approach matched the best neural network formulation but

avoided the need for training sessions required for neural network development. It also enabled a reliable estimate of confidence in the proposed dispatch that the neural network solution lacked.

Fire Suppression

There have been no significant efforts to develop fire suppression decision support systems in Ontario other than Doan's (1974) work and Hirsch and others' (1998) development of a framework for encoding subjective assessments of initial attack firefighter productivity.

Project Fire Management

Fire managers assigned to large fires have a suite of laptop computer-based tools, such as the Fire Weather Index and Fire Behavior Prediction Systems, to assist their efforts. However, there has been very little work on the development of comprehensive DSS's for evaluating project fire management strategies and tactics in Ontario with the exception of Saporta (1995), who developed a prototype escaped fire situation analysis system. A geographic information system (GIS) is used to delineate a specific escaped fire and subjectively assess potential final fire perimeters, which are assigned subjective probabilities of occurring. The GIS descriptions of the final fire perimeters are linked to a forest level timber harvest scheduling model, which is used to assess the long term implications of each possible fire size on timber management in the forest. The OMNR has developed internally a set of "Comptrollership Tools," primarily spreadsheet templates and decision-trees that can be used on large fires, to assist with assessing the costs and impacts of decisions pertaining to base camp locations, fire service strategies, and demobilization schedules.

Level of Fire Protection Planning

The fire load reduction systems and the fire response systems must be designed to provide a level of protection that is compatible with strategic land management objectives. The OMNR, like many other forest fire management agencies, is now focused on strategic level of protection planning. It is well aware that it is neither economically or biologically desirable to exclude fire from forest landscapes and is developing and implementing planning procedures that relate levels of fire protection to strategic land use management objectives. Martell (1980) developed a stochastic optimal stand rotation model and used it to produce a very rough estimate of a hypothetical fire management agency similar to the OMNR, but stand level analyses are of questionable value for forest level policy analysis. Martell (1994) used Reed and Errico's (1986) forest level timber harvest scheduling model to assess the impact of fire on timber supply in Ontario. Boychuk and Martell (1996) used stochastic programming methods to determine how forest managers can explicitly account for probabilistic fire losses when they trade off harvest levels, economic returns, and harvest flow stability. Martell and Boychuk (1996) prepared a level of fire protection discussion paper that was used to help stimulate level of protection discussions in Ontario.

The initial attack simulation model (IAM) developed by Martell and others (1984) was later modified to meet the needs of another forest fire management agency and subsequently updated by Martell and others (1995) to produce Lanik, a modern desktop computer implementation of IAM to facilitate its use for strategic level of protection planning in Ontario. Lanik includes links to a database management system to facilitate the management of both input and output data. Lanik was later extended and embedded in a GIS to produce a model called Leopards (McAlpine and Hirsch [this volume]). Leopards has been used for a variety of purposes including an assessment of the potential implications of climate change, changes in initial attack fire crew staffing levels,

and the up-grading of the airtanker fleet with modern CL-415's. OMNR staff and others drew upon Reed and Errico's (1986) harvest scheduling model to develop the Strategic Forest Management Model (SFMM), which is now used extensively for forest management planning in Ontario. SFMM is emerging as an important link between the OMNR's fire organization and other forest management agencies and is expected to foster a significant improvement in the extent to which level of fire protection policies are assessed from broad land use management perspectives.

Fire Management Information Systems

Fire managers cannot fully exploit decision support systems technology unless they have a comprehensive fire management information system in which they can embed their DSS applications. Kourtz (1994) points out that decentralized organizations have little need for advanced information technology but centralized organizations cannot function effectively without it. He indicated that centralized control calls for monitoring the changing fire environment; predicting potential fire occurrence, behavior, and suppression work loads; deployment of suppression resources to minimize initial attack response times; allocating detection resources to ensure timely detection of new fires; and dispatching initial attack resources to minimize the expected number of fires that escape initial attack.

Fire Report and Fire Weather Record Processing

Like many forest fire management agencies, the Ontario Department of Lands and Forests began batch processing of its basic fire report information in the 1960's and continually refined it to the point where it is now embedded in the Daily Fire Operations Support System (DFOSS) fire management information system. The Department of Lands and Forests began archiving its fire weather data in a computer readable format in the 1970's. Doan and Martell (1973) describe the interactive mainframe computer system that was used to combine weather forecasts provided by meteorologists with fire weather observations collected at fire weather stations to produce daily observed and forecast values for the indices of the Canadian Forest Fire Weather Index System, the fire danger rating system that is used in Ontario. The system evolved from the use of telex machines as input and output devices linked to a central mainframe computer through the introduction of local calculations on first-generation microcomputers, to the use of regionally-based minicomputer-terminal systems, and to the current client-server architecture now in place across the province.

Fire Occurrence Prediction

Fire occurrence prediction systems provide essential information for managers who must decide how to allocate their detection resources and deploy and dispatch their fire suppression resources each day. Cunningham and Martell (1973) showed it is reasonable to assume the probability distribution of the number of people-caused fires that occur in an area each day is Poisson with a mean that varies with the Fine Fuel Moisture Code (FFMC), a component of the Canadian Forest Fire Weather Index System. Cunningham and Martell (1976) developed a methodology for eliciting subjective probability assessments concerning forest fire occurrence from experienced local fire managers. Martell and others (1987) used logistic regression methods to facilitate the inclusion of other fire danger rating indices in the model, which was further extended by Martell and others (1989) to model seasonal variation in daily fire occurrence. Those methods are now used to produce daily people-caused fire occurrence predictions in Ontario.

As early as 1973 Kourtz field-tested people and lightning-caused daily fire prediction models at Dryden in northwestern Ontario. He used a network of about 20 short-range lightning counters that produced daily observations, which were combined with estimates of the moisture content of medium-sized fuels (represented by the Duff Moisture Code of the Fire Weather Index System) to produce a daily forecast of lightning fire occurrence. His daily people-caused fire prediction model was based on correlations between historical occurrence and daily fire weather indices. Todd and Kourtz (1991) partitioned the protected area into 100 to 200 square km cells and used correlations of historical fire occurrence and fire weather data to predict average daily fire occurrence in each cell. Kourtz's (1989) people-caused fire occurrence predictor combines expert opinions concerning many factors that influence fire occurrence processes (e.g., land use patterns and fuel type data) provided by fire managers, with fuzzy logic, to produce daily people-cause fire occurrence predictions. Later he explored the use of neural networks to process such inputs for daily fire occurrence prediction purposes.

Kourtz and Todd (1992) developed a daily lightning fire occurrence prediction model that uses fuel moisture and lightning stroke data to predict fire ignitions. The hold-over smoldering process is modelled to predict how many "detectable" fires are burning undetected in an area each day. Kourtz's more recent work on lightning fire prediction involved the correlation of historical patterns of indicator variables with actual fire occurrence. Here, the pattern space was encoded as a sparse distributed memory and loaded with historical observations. Each new day, the current input pattern was matched in the memory and the most appropriate prediction of lightning fires made. It is an adaptive system in that each new day's input pattern and resulting fires are cumulated in the system's memory.

Kourtz's Prototype Fire Management Information System

Kourtz (1994) and his colleagues worked closely with a number of Canadian forest fire management agencies, including the OMNR, to develop and test a prototype fire management information system that is designed to use modern information technology to support cost effective centralized fire control. Although no particular agency is using the complete prototype system, many have adapted parts of it to fit within their own systems and have benefited from the considerable knowledge and experience gained during the development and testing of the components. The basic system described in Kourtz (1994) includes information acquisition, storage, and retrieval capabilities to process hourly and daily weather data, fire report data, detection reports of new fires, current and predicted fire weather and fire danger rating indices, fuel type maps, fire behavior maps for the current and predicted weather, lightning strike locations, fire occurrence prediction maps, digital or analog terrain maps, initial attack resource status, current aircraft location, physical features such as roads, lakes, rivers, boundaries, and detection planning system maps.

Kourtz's (1994) prototype system also includes many decision support subsystems designed to help managers resolve particular problems, including the daily people-caused fire occurrence prediction, daily lightning fire occurrence prediction, initial attack dispatching, and daily detection planning components.

Ontario's Current Fire Management Information System

In 1990, the OMNR began a comprehensive review of its fire management information needs, culminating in a feasibility study (OMNR 1991) that outlined the evolution of the information system from its aging minicomputer-terminal architecture. That study suggested a four-layer structure beginning with basic data collection and management, the preparation of primary information products, such as fire weather indices and fire behavior indices, and then advancing to more complex tactical and strategic decision support tools, such as

Table 1-Structure of Ontario's Fire Management Information System.

Strategic planning layer	Level of protection analysis system	Resource allocation models	Fire impacts analysis system	Performance measures assessment system	Natural resource supply models
Tactical planning layer	Resource deployment and scheduling systems	Initial attack coverage/ response time assessment systems	Initial attack dispatch support system	Detection planning and routing systems	Fire growth/ suppression effectiveness models
Daily information management layer	Fire weather index system	Fire behavior prediction system	Fire occurrence prediction systems	Resource tracking and utilization systems	Cost management systems
Data acquisition and management layer	Weather/lightning data management system	Incident and fire data management system	Values and fuels data management systems	Suppression resources data management system	Cost data tracking systems

fire occurrence prediction, resource deployment models, and level of protection planning (*table 1*).

The OMNR's DFOSS replaced an earlier decision support system in 1993 and was the first major product to arise from the FMIS feasibility study. DFOSS is a client-server system with more than 100 Macintosh⁶ workstations located in 30 fire management offices, linked to a central VAX/Alpha-Oracle server. DFOSS is used to capture and manage daily weather, fire and lightning data, and provides access to decision support systems for daily planning, weather analysis, fire behavior, and fire occurrence prediction and cost tracking. It has components that generate a wide variety of maps and reports. DFOSS contains various tools and sub-systems.

DFOSS was developed through an extensive user-consultation process designed to create an application that was easy to use, supported the daily operational needs of its users-sufficiently robust to deal with contingencies such as hardware failures and network outages-and could be operated from remote locations. The OMNR is currently migrating DFOSS to a new technology architecture and expanding its capabilities. In phase one, DFOSS data will be linked in real-time to its server network. Analysis and decision support tools will be migrated or new tools developed to access the data through the NT-servers; subsequently, the transaction processing/data capture applications will be migrated to the new environment. DFOSS addresses a number of the cells shown in the FMIS Structure Matrix (*table 1*). Other components are also now in place, such as the Fire Equipment Management Information System (FEMIS) for tracking and managing fire suppression equipment, and other developments are underway or planned to address the other components of the FMIS matrix.

Some Lessons Learned in Ontario

Collectively, we have been actively involved in the development, testing, and implementation of fire management decision support systems in Ontario for more than 25 years. We have had some successes, made many mistakes, and learned a great deal along the way. Many of our experiences are consistent with what operational researchers (OR) have reported in other areas, but we found some aspects of fire management to be a little different than the organizations others have described in the literature. The OR literature stresses the importance

⁶Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

of gaining the support of senior management and having a senior manager champion OR projects. Some practitioners suggest operational researchers should begin there and rely on those senior managers to bring the organization along. Our experience differs. We found it was essential to convince middle managers that DSS will enable them and their colleagues to do a better job. We found that if and when they accept these DSS tools, they will convince senior managers and garner their support and the commitment of resources that is needed for them.

We believe researchers have to go to the field to find out what is going on "on the forest floor," to identify the needs of fire managers, and to stimulate their thinking. They must go beyond simple field trips and spend extended periods of time working alongside fire managers and studying what goes on. If they do so they will find interesting opportunities or problems fire managers might not otherwise bring to their attention.

Until very recently, almost all of the DSS research and development that took place in Ontario was carried out by researchers who conducted both basic and applied research in collaboration with OMNR staff. The OMNR staff played many roles, including facilitator, project manager, and in some cases, they were collaborating researchers. The OMNR was very cooperative and actively supported applied research they expected would benefit them in the near future, as well as more basic research that was of little apparent practical significance in the short run. That enlightened stance made Ontario a desirable place to carry out research on fire management decision support systems that benefited both the OMNR and the researchers involved.

One cannot measure success by documented implementations of specific decision support systems alone. Most projects carried out in Ontario, including many of those that "failed," provided valuable learning opportunities for both DSS specialists and fire managers, and all, to some extent, contributed to the development of knowledge, understanding, and expertise that has brought us to our current position. The most significant impact of the OMNR's DSS initiatives has been the development and widespread acceptance of a decision analysis culture within the OMNR's fire organization. Forest fire managers in Ontario recognize the need to augment their traditional reliance on training, experience, and intuition with formal decision analysis but the OMNR's fire management community now includes many informed OR consumers that use models developed by others and in some cases, develop and use their own models.

The OMNR has made a very significant and persistent commitment to modern information technology, and it has invested a great deal of time and money in research, development, field testing, and the implementation of computer-based decision support systems. It is clear that it has benefitted and, given past successes and future needs, we expect the OMNR will continue to play an active role in this area for many years to come.

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A Forest Fire Simulation Tool for Economic Planning in Fire Suppression Management Models: An Application of the Arcar-Cardin Strategic Model¹

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Abstract

Simulation of dynamic fire spread behavior of forest fires provides important information for decision-making. Specific programs facilitate the option of analyzing the energetic characteristics and spatial developments of fire spread, as well as the potential results. By simulating strategic attack and suppression plans through resource positioning to control and extinguish forest fire, decisions can be validated before their execution. In economic analysis terms, the simulation offers the possibility of valuing the cost of different suppression strategies and preventive planning associated with vegetation management, such as qualitative and spatial change of fuel models. The simulation model, Arcar-Cardin, is a capable tool for defense programs against forest fires. The organization and structure of the program at the user level and the procedure plan for personnel is presented in this paper, as well as the program's practical application to help prevent and extinguish forest fires.

Introduction

Technological developments in the field of data processing have permitted the elaboration of simulation programs of great versatility and usefulness, offering a multitude of alternatives as tools in decision-making. These specialized simulation programs should be capable of facilitating information about the dynamic behavioral forecasts of fires that evolve in different forest ecosystems.

In 1989 the first version of a forest fires simulation program, designated Cardin (Martinez Millan 1991, Martinez Millan and others 1996), was developed. The simulation program has evolved and improved as it has been used by the organizations that specialize in detecting and preventing forest fires. A conversion program has been developed, Arcar41, that transforms the ARC/INFO³ data in geographic information systems (GIS) into the file formats required by Cardin to simulate forest fires. This program includes a set of enforceable components in turbo-basic and files of macros written in SML language of ARC/INFO. Initially, a specific program was designed to be used with Cardin, known as "cartographic digitalizations" (Digicar); however, because GIS has more advanced functions and information already elaborated under its data processing structures, a conversion program that uses both GIS and the Cardin simulation program helped us to obtain a savings in cost, effort, and time. The simulation program uses the 13 fuel models of the BEHAVE system used by the USDA Forest Service (Anderson 1982) by adapting them to the Mediterranean ecosystems. The advance of the fire is reproduced as a function of the digital terrain model and meteorological characteristics. Adjustments to local conditions causes the fire perimeter shape to change.

Strategic Planning of the Arcar-Cardin Model to Simulate Forest Fire Behavior

The development of the fire is verified in the Arcar-Cardin program on a zone of 400 by 400 pixels, which consists of four map modules, each 20 by 20 cm,

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³Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

identified with the universal transverse mercator (UTM) geographics reticle. The simulation begins by establishing an ignition area or ignition line that uses a set of pixels. For each pixel, a value of maximum slope and direction is determined via mathematical calculations based on the digital terrain model.

The rate of spread in the address (a) is determined with the following equation:

$$V\alpha = (V_0 + V \cos(\alpha - a))Fw$$

in which ($V\alpha$) represents the spread rates for a given fuel, with zero wind and horizontal area; (a) represents the angle constituted by the pending maximum address with the north of the UTM reticle; (V_0) represents the spread sheet and the joint effects of the wind and slope; and (Fw) represents an adjustment factor of the burned area that is determined by the quotient between the broad maximum calculations obtained from BEHAVE and from the theoretical figure based on the spread model from the Cardin program.

The program operates by using a disk-operating system (DOS) and is programmed in turbo-basic. The simulation of fire spread is accomplished from analysis of the times that would delay the fire's advancement in each one of the cells contiguous to the pixel already burned. Before this analysis, if the program shows that the cells have already burned, they are not included in the analysis. These pixels can be studied by the spread model from different roads, depending on the origin of the combustion evolution. This is translated in the appearance of an angle (w), which develops differently. The pixels that are found active in each time (t) define the profile of perimeter of the fire developing.

Modular Structure of the Program

The program begins with a principal menu displayed horizontally in the upper part of the screen, offering users different components or options that can be added to the simulation and that are displayed vertically on the screen. The program can establish a new simulation, use the last developed, or use a stored file in a directory of previous simulations. This capability allows an itemized analysis of possibilities to extinguish a fire. All simulations can be saved to a stored directory file established by the user. This permits an itemized analysis of the extinction of the fire. All accomplished simulations can be saved in the place indicated by the user.

Before starting a simulation, it is necessary to define a virtual space where the program can calculate temporary files that will then become permanent files as the steps progress in the simulation. After the option is selected to create the virtual space of the simulation, the user can adjust the conditions of the environment by defining the colors that will correspond to the fuel models, which establishes a framework in which the user can develop and store the simulation.

The "initial user" option contains the command "colors," which can be used to assign and change the colors initially assigned to each one of the polygons of the different fuel models. The "monitor" option controls the value of the diagonal of the monitor in inches, which calculates the scale of the graph. The "directory" option allows the user to access the directories of previous simulations stored in the program.

The main menu includes the set of characteristics that a user needs to establish a simulation. These characteristics include "map" options of several operative map modules and a "name" command that establishes the simulation. The UTM reticle can be coordinated and digitally manipulated directly on the screen, and various components, such as soil, flammability, and cartography, can be selected to define the initial components of the simulation.

A "parameters" module incorporates the data associated with local characteristics, such as the "wind" command, which includes direction and speed that can be measured down to 6 m on the area. The "humidity" command

assigns the level of dampness, and live or dead fuels can be classified by their geometric characteristics. In addition, by using this procedure the dampness of the dead fuels can be obtained as a set of calculations based on data such as the date, meteorological effects, and the area and state of the vegetation. The "cover" command assigns the degree of protection from the flammable front of the wind. The "residence" command establishes the possible set of flames and embers assigned to the different fuel models. This command simulates the combustion process as a result of windspeeds.

The fourth module contains the specified instructions to execute the simulation. Before the module is executed, alternative options can be selected that either correspond to the automatic defaults of the program, or the user can stop the simulation manually at time intervals that are entered into the simulation program.

The program offers the possibility of using the cursor to introduce barriers, such as fireproof fronts, to the dynamics of the fire spread. The "report" command obtains data and information that the user specifies on any cell of the screen, such as UTM coordinate, slope, aspect, vegetation cover, fuel models, speed and wind direction, access time of the fire to the cell, and maximum spread rate in the cell with respect to combatting the fire. This information can be altered by the user to reduce the dangerous characteristics of the fire spread.

Arcar-Cardin is capable of generating the simulation effects to intervene, control, and extinguish the fire. The program is extremely useful in its ability to measure different fire management strategies and the equipment resources needed to implement the strategies. To simulate the suppression actions of infrastructures, firefighting resources, yields, and communications, data chips can be created and imported from the database by using the program "GFUEGO" (file:*.DBF) that can function independently of the Arcar-Cardin program.

The fire fighting resources include firefighters (transported by land or air [helicopter]), fire engines, machinery for land movement, amphibious air tankers, air tankers, and fire fighting helicopters. It is possible to use the entire set of resources in the simulation because of the real yields for the resources. The program uses this information in the cells by establishing the corresponding values of the individual rates for each type of resource.

Arcar-Cardin incorporates a relative module into images that can be set in two or three dimensions. If the user wishes to use two dimensions, zones of 200 by 200 pixels are established for flame length, directions, residence of the flame, wind maps, fireline intensity of the flame front, heat by unit area, and rate of simulated spread.

Applications of the Program

The Arcar-Cardin simulation program has a number of practical applications that attest to its usefulness in fire management. First, the program is useful because it can generate knowledge of potential fire behavior forecasts, which allows fire managers to adapt fire attack plans so that they are more successful.

Second, the program is also helpful to fire managers because it can help identify defense infrastructures (fuelbreak) and transform fuel models so that a forest can be managed to prevent forest fire. Arcar-Cardin tests and confirms preventive silvicultural strategies that have been used to hinder forest fires.

Third, Arcar-Cardin can be used in post-analysis of a fire. It can reconstruct the fire behavior and verify results obtained by the different attack plans to extinguish the fire. This feature can be used in final reports on the nature of a fire and the evaluation of the effectiveness of the resources used. This information can be used to set up training courses on fire behavior and fire suppression.

The use of the program within a fire planning area is directed from a Regional Command Center. Given the large amount of geographic information that establishes the work environment (digital geographic models, forest fuel models, infrastructures, etc.), it is necessary to have adequate computer storage to manipulate the necessary information in the simulations.

The great advantage of Arcar-Cardin is its ability to simulate the fire behavior of an active fire with or without resource intervention. The results of different strategies can be analyzed before mobilizing actual resources to extinguish a fire. The selection of various options and resources in a simulation is a very efficient tool for fire management.

The selection of the resources for an efficient initial or extended attack plan is established by following these procedures:

- *Initial Phase:* Visual analysis of the digital terrain model, fuel models, uses of the soil and of positioning of the infrastructures, roads, and fire prevention.

Determination of the complications that the forest area presents to the control and suppression of the fire (suppression index).

Simulation of the spread without the intervention of resources by obtaining the spatial structure of the advance and development of the forest fire. Elaboration of alternative spread dynamics by using different meteorological situations that could be representative of a zone in different hours of the day.

Obtainment of the surface perimeters affected under different meteorological conditions and of topographic influence.

- *Final Phase:* Checking the data base of the available resources in the proximity of the fire.

Distribution of the resources in the fire according to the initial attack plan.

Intervention of simulated resources compared to the real fireline production rates to determine the correspondence of the simulation results to the actual results.

Determination that the resource equipment provided in the simulation was the most effective containment strategy to hinder the dynamic spread of the forest fire.

The simulation of an attack and control of fire by using different resources results in cost estimates of the different scenarios. The economic analysis provides information on those bottom line resources that can hinder the dynamic spread of fire, and it provides important information about the costs of different resources used to fight a fire.

The data obtained from the economic analysis of fighting a fire is a valuable tool for evaluating the effects of a fire on a particular area. This analysis provides information for evaluating the effectiveness of an attack plan and different contingency plans to combat fires.

Arcar-Cardin can provide information about fire behavior that might evolve as a result of the different combinations of fire attack and the resources used. To develop a record of the economic impact of the suppression activities, it is necessary to keep track of the value of certain parameters associated with all resource used. These parameters are:

- Containment rate of spread (CRS): This parameter is obtained by comparing the relationship between the time it takes a specific resource to stop the fire rate of spread, in a specific zone of the perimeter, compared to the spread rate without the same resource intervention.
- Opening defense lines (fireline production rates, FPR): This parameter collects data for each individual resource about the linear meters of line constructed by unit of time.
- Hourly cost of the resource (CHR/s): This parameter is a calculation of the surface area that a resource is capable of protecting.

- Down times (DT) within period of anticipated performance: This parameter collects the total time that a resource is unavailable as a result of breakdowns, short moments of rest, travel times, fuel reloads, etc.

The results obtained from the detailed analysis of combinations of the four parameters allows fire managers to more efficiently select the resources needed to combat a fire. Throughout the simulation the effectiveness of alternative firefighting equipment can be tested, which offers greater efficiency in the actual control of a fire.

Real Application of the Simulations

The simulation program is currently used in Andalusia, Spain, by the Regional Command Center to Fight Forest Fires. The methods used to implement the results of simulations of the Arcar-Cardin program follow this sequence:

- Detection of the fire.
- Communication from the Provincial Command Center to the Regional Command Center.
- Dispatch of the initial attack group.
- Use of a global positioning system (GPS) to obtain geographical coordinates and to evaluate the situation.
- Establishment of the parameters needed to accomplish a simulation (fuel models, topography, infrastructures of fire prevention).
- Creation of the work modules of 200 by 200 pixels.
- Input of the initial data required to develop the simulation.
- Development of the simulation without activating the suppression module.
- Development of the simulation with the firefighting equipment needed to fight the fire based on economic information.
- Elaboration of the conclusions of the accomplished simulations. Shipment of the performance plans simulated to the command post of the fire and to the Local Command Center.
- Determination of the economic value of the intervening resources by compiling a final report after the control of the fire that compares the differences between the operations prescribed by the simulation and the successful use of the work equipment.

The results obtained from a simulation can be used to build a database in which the surface area of a fire is allowed to spread without the inclusion of the suppression resources. The purpose of this function is to simulate an actual fire to obtain the surface area after the control of the fire. The quotient between both surfaces determines the rate of control of fire spread. This parameter facilitates information about controlling a fire in similar, real environmental conditions. This historical knowledge provides fire managers with a set of effective resources for controlling and extinguishing a forest fire.

In Andalusia, Spain, the program Arcar-Cardin is being used as a tool to simulate prescribed burns before they are implemented. The results provide information about the parameters of fire behavior, facilitating statistics on the value registered in each cell in the rate of spread, flame length, heat by unit of area, and fireline intensity of the front. This information can be used to determine the number and types of resources necessary to meet safety criteria. These simulation results also provide fire managers with the amount of funds needed to prevent and extinguish forest fires.

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Improving the Economic Efficiency of Combatting Forest Fires in Chile: The KITRAL System¹

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Abstract

Forest fires in Chile are a very important problem that affects both the environment and forestry activities. The national government started systematic programs to combat this affliction in the sixties; in the seventies, private companies also started their own programs, looking for an improvement in the continuously growing problem with forest fires. Since the beginning of the first fire management program, there have been important improvements, particularly in effectiveness. Chile has 30 years of experience at several levels, particularly at the operational level, and in the upper levels of fire management organizations. However, effectiveness has not been accompanied by efficiency. In the past 15 years, effectiveness (average fire size) has remained fairly constant, but the budgets have been steadily growing, even when analyzed in terms of money spent per hectare. Improving efficiency in fire management seems to be a very straightforward process that would focus on reducing the fire combat resources used in a fire to the necessary minimum to avoid overspending. The problem with this approach is that it is very hard, if not impossible, to estimate the minimum number and type of combat resources without adequate information. The KITRAL ("fire" in indigenous Chilean language) system was designed and built as a management support tool to avoid guessing and reduce uncertainties. It contains two basic components: an extensive geographical database; and a set of algorithms, functions, and procedures to compute and predict, via simulation models, the fire behavior at several time and space scales, including risk, danger, fire model, spread rate, wind velocity, priorities, flame length, heat yield, etc. A very important issue in KITRAL design was the price and reliability of the computer platform, not only in terms of the initial purchase but also in terms of maintenance, down times, technical support and spare parts costs. In addition, because of its potential use in remote locations, the hardware ought to be movable, portable and, ideally, field operable. KITRAL has an interactive user interface built with two objectives: user friendliness and fast response. Although KITRAL can be improved, its first operational season showed good results, some of them very impressive. However, information and forecasts can only help to make better decisions; ultimately, the resulting actions will control the fires. During the first operational season, the forecasts delivered by KITRAL demonstrated that in the operational level, the costs of combatting forest fires could be reduced notably, through a better estimate of the number of units dispatched for the first attack. Thus, because the KITRAL system improved the efficient use of resources, it will contribute to reducing fire fighting budgets.

Introduction

Forest fires are a significant threat to the conservation and appropriate management of the renewable natural resources in Chile. They have been an important problem since the occupation of the different Chilean regions: mid-19th century for the southern section (37° to 42° S latitude) and beginning of this century for the far south regions (42° to 54° S latitude).

According to unofficial estimates, about 15 million hectares were destroyed by huge forest fires until the fifties, primarily because of land habilitation for agricultural and cattle raising use. Because of the initiation of protection programs in the sixties, agricultural burns were heavily regulated, and currently represent about 10 percent of all fires. However, in the past 30 years, about 1.35 million hectares of rural land have been damaged by fires, primarily because of

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human neglect while traveling or transporting, recreation and tourism, and farm (forestry, agricultural, or cattle raising) activities. Chile has also experienced an increasing number of arsons.

It is estimated that forest fires are one of the primary factors in the destruction of the renewable natural resources because of the natural characteristics of Chile's landscape, which consists of a very abrupt topography, almost permanent wind, and a hot and dry summer. Another important aspect is the high population density in urban centers that creates high-risk areas in the peripheral zones because of the human activities, behavior, and attitudes.

The extensive damage and casualties caused by forest fires in the 1960's resulted in the establishment of a national fire management system to prevent and combat the problem. In the late 1970's, several private forestry companies started their own systems. These systems have grown and consolidated on the basis of acquired experience and the increasing allocation of financial resources. A very important aspect of the achieved results is the expanding cooperation among private and public entities in all activities related to forest fire protection. There is also an effort to include research and development organizations in the national agenda to manage forest fires. This cooperative effort is oriented to attack the problem from several points of view that must be considered in this complex activity. In this framework, the newly created KITRAL system is a consequence of the need for more efficient management schemes to mitigate the damages and losses provoked by fires.

According to the available data from the National Forestry Corporation (CONAF) fire management statistics system and other sources (Forest Police and the University of Chile), Chile has kept forest fire records since 1962 (*table 1*; Julio and others 1998). The records show a dramatic increment in the occurrence of forest fires in the three initial 5-year periods, whereas the number of forest fires became stabilized in the last three (*table 1*). This might be explained by poor capability to capture and record occurrence data in the 1960's and 1970's. In the last three 5-year periods only, data became reliable, and the annual rate increased 1.4 percent.

The reduction of the annual increase rate is also the result of prevention campaigns and better control in the use of fire. Forest fire occurrence is also increasing worldwide, as a consequence of the expanding use of renewable natural resources, either as an economically productive activity or for recreational purposes, which significantly increase forest fire risk. This increase particularly occurs in areas where human neglect or intentional activities have caused forest fires.

An increasing trend is also found for the total burned area (*table 1*). However, assuming that the data from the initial 5-year periods is incomplete, the actual trend is a constant value.

The average fire size shows a steep drop in the initial 5-year periods (*table 1*), which, doubtlessly, was a consequence of the creation of formal protection programs. These programs resulted in the generation of structures and organizations to effectively presuppress and combat the fires, which received the highest proportional increment in the resources assignment. In 1981, this indicator fluctuated between a constant value, attaining its best results in the 1990 / 91 to 1994 / 95 period.

Table 1-Forest fire occurrence and annual averages for six 5-year periods in Chile.

5-year periods	Average number of fires	Average burned area (hectares)	Average size of fires (hectares)
1965/66-1969/70	497	26,875	54.1
1970/71-1974/75	1,238	37,203	30.1
1975/76-1979/80	3,157	36,092	11.4
1980/81-1984/85	4,995	46,482	9.3
1985/86-1989/90	5,026	67,022	13.3
1990/91-1994/95	5,531	43,251	7.8
Total	102,220	1,284,625	12.6

By using the data in CONAF's fire management statistics system, the vegetation affected by fire was summarized (*table 2*; Julio and others 1998). Another important aspect to consider is the evolution of the causes of forest fires (*table 3*; Julio and others 1998). The data show a significant change on the risk agents during the last four 5-year periods. *Table 3* shows a very clear decrease of importance of burns on forest fire occurrence. On the other hand, pedestrians have been increasing their risk level. The increase rate of arsons has become the most important cause for forest fires.

Direct fire damage and budgets for fire control were estimated (*table 4*). The data was compiled by the KITRAL project from several sources: previous research conducted by the University of Chile, CONAF data, and information from the Forestry Institute and the private companies (Julio and others 1998).

An increasing trend was found on the budget allocation for the fire management system as a whole (*table 4*). Both, the private and public sectors have steadily increased their expenses, with the exception of the period 1970 to 1985, when the public budget was fairly constant. The data show annual increasing rates for the total, fiscal, and private costs of 14.86 percent, 2.16 percent and 20.16 percent, respectively, for the whole period (*table 4*). In the past 15 years, the respective total, fiscal, and private cost increases are 6.44 percent, 4.51 percent, and 7.98 percent, respectively.

Table 2-Vegetation types burned in Chile, 1972-1995.

Types	Area (hectares)	Percent
Radiata pine	114,883	10.17
Eucaliptus spp.	24,723	2.19
Other plantations	2,718	0.24
Native forests	228,109	20.19
Shrubs and bushes	372,658	32.98
Grass	352,368	31.19
Others	34,337	3.04
Total	1,129,796	100

Table 3-Evolution of the causes of forest fires in Chile.

Fire causes	Percent of fires (5-year periods)				Total (percent)
	1976/80	1981/85	1986/90	1991/95	
Burns	41.4	23.9	16.8	10.0	20.2
Forest works	3.8	3.5	2.9	1.5	2.8
Agricultural works	1.4	2.2	2.1	0.9	1.7
Recreation and sports	4.8	3.5	3.2	2.6	3.3
Children playing	12.0	8.8	11.0	8.0	9.6
Railways	4.6	3.6	1.9	2.2	2.8
Transit of vehicles	2.0	2.0	2.1	1.9	2.0
Pedestrians	14.2	27.8	31.8	33.0	28.2
Other negligence	1.0	2.5	1.5	1.2	1.6
Arsons	13.3	21.0	24.8	37.0	26.1
Naturals	0.1	0.0	0.1	0.0	0.1
Accidents and others	1.4	1.2	1.8	1.7	1.6

Table 4-Fire damage and budgets from forest fires in Chile¹

5-year periods	Direct damage	Budgets		Total budgets
		State	Private	
1965/66-1969/70	22,757	1,532.8	584.9	2,117.7
1970/71-1974/75	19,937	2,900.6	1,902.2	4,802.8
1975/76-1979/80	31,404	2,815.2	2,600.1	5,415.3
1980/81-1984/85	30,879	3,019.9	3,449.9	6,469.8
1985/86-1989/90	60,847	3,609.9	5,560.6	9,170.5
1990/91-1994/95	32,355	4,922.8	8,079.9	13,002.7
Total	990,895	94,006	110,888	204,894

¹Annual averages in thousands of U.S. dollars, January 1995.

Another interesting fact is the distribution of the total fire management expenses. From 1962/63 until 1994/95 the fiscal contribution decreased progressively from 90 percent to 38 percent. Conversely, private participation increased from 10 percent to 62 percent. In the 1979/80 season both sectors showed a similar level of expenditures.

In the last four 5-year periods, forest fire damage has remained at a similar level, with the exception of the period 1985/86 to 1989/90, during which (specifically in 1987/88) record breaking losses affected some 20,350 hectares of planted forest (*table 4*).

The constant increment of the effort in fire management, at least during the last three 5-year periods, has not produced any evidence of damage reduction nor an increment in protection efficiency (*tables 1-4*). Given this finding, we can conclude that the constant increment of protection expenses has not been focused on improving the fire management systems. In fact, these systems have not experienced any significant technological improvements in the past 15 years; there is a historically prevailing "firefighter" style that has not been overcome. In other words, forest fire development in Chile has been physical and not qualitative in which decision-makers have preferred to increment the number of detection towers, combat brigades, choppers, etc. and lessened other fundamental aspects such as prevention, training, and research, which have jointly received resources for less than 5 percent of the total budgets.

In addition, planning schemes or information systems to support fire management have not been developed appropriately. This has resulted in subjective decisions, without an acceptable base at the operational level when confronted with an unusual situation, as well as at higher organizational levels dealing with a structural problem. In other words, the problems with the efficiency level in fire management do not essentially reside in the number of available resources but in their correct definition and the way they are assigned and used.

The KITRAL System

The KITRAL system was developed by a consortium of the University of Chile and the Forest Institute and the Technological Research Institute of Chile (INTEC-Chile) as an effort to improve the efficiency of the fire management programs that operate in Chile. This system represents an important technological innovation for the permanent evaluation of the problem of forest fires and permits the use of tools for management and control (Proyecto FONDEF FI-13, 1995).

The principal objective of the system is to improve the efficiency of the fire management by analyzing the conditions that affect the occurrence and damage of fires, and the use of devices to evaluate and define options in decision-making for prevention and fire fighting, as well as for strategic planning.

KITRAL is an information system that includes geographical databases and simulation models with algorithms based on mathematical models developed in Chile. The principal characteristics of its technical implementation are simplicity and its response speed to high complexity situations. For example, the simulation of a fire that spreads in 12 hours is obtained in minutes. Its operation is accomplished through independent and connected modules that solve various global and specific questions to manage fire.

The KITRAL system is original because its design has been adapted to the conditions of Chile, with databases and standards of productivity that are tailored to fire management programs operating in Chile. It also possesses unpublished modules related to the strategic planning and management mechanisms; and it uses the results of the investigation accomplished from 1967 in Chile. Nevertheless, the design and architecture can be used by other countries by replacing the databases and the productivity standards with those of another country.

Administration and Analysis of Geographical Information

A geographical information system (GIS) stores the spatial information (vegetation, topography, climate, hydrography, roads, populations, fire occurrence, infrastructure for the fire management, etc.) and facilitates their use and transfer to other modules of the system. Its functions include:

- Maintaining updated information such as the operations zone of the managing program of the fire to permit the operation of the simulators and to inform the dispatcher on the situations generated in sectors affected by fires. The information includes data on accessibility, fuel models, topography and, the availability and location of the resources under the responsibility of the program.
- Estimating the probability of forest fire occurrence for the whole operations area and the conflict levels of the contingent fire areas that are produced.
- Modeling fire spread and issuing further information on perimeter, surface, behavior of the fire, probable losses and work load required for the containment of the fires.

System of Operational Command

To support decision-making for the allocation and mobilization of financial resources, KITRAL uses two systems:

- Daily operation scheduling-This subsystem optimizes the daily assignment of mobile resources for presuppression and fire fighting by using the Protection priorities for the coverage zone and the Risk Index. These are calculated from meteorological data of the previous day and the forecasts for the day. The optimization process is executed by balancing the theoretical work load between equivalent units.
- Dispatch-This subsystem detects the location of the areas of reported fires. This permits the simulation of the spread and conflict of the fires and allows the calculation quantities and types of resources that should be sent to efficiently fight the fire. At the same time, this subsystem records all the actions in the databases of the statistical subsystem.

Subsystem of Resources Optimization

To optimize resources, KITRAL facilitates the spatial distribution of the available resources for the prevention and presuppression of fires by analyzing various stages of protection supply and demand, for the average and long term. The processes consider the combination of protection priorities, the efficiency standards of the available resources, and the coverage of the different types of resources (detection towers, fire fighting brigades, centrality of supplies, etc.).

Statistics Subsystem

The statistics subsystem fulfills two functions: SEARCH and RECORD. SEARCH allows the user to make queries to the databases. RECORD allows users to record the compiled information about each one of the forest fires during the season. These functions allow users to obtain information on fire occurrence, burned area, resources used (fire fighting), and dispatch instructions. These are saved automatically to an electronic log.

Impacts of the KITRAL System

Projected savings by using the KITRAL system ranges from 15 to 50 percent. Installation costs are only 3 percent, which can be recovered rather quickly by a

more rational use of fire fighting resources fighting resources and a corresponding reduction in fire losses (Julio 1998).

Application of the KITRAL System

KITRAL can be used to sustain dispatch decision-making by considering the quantity and the type of available resources for firefighting. We will illustrate this by using an example of a forest fire that occurred in the 9th Region of Chile, near Concepción City, during the season 1996 / 1997.

The fire caused a total burned area of 410 ha in which 116.5 ha were adult radiata pine and eucalyptus plantations belonging to private forest companies and others. The accident caused one million dollars in damage according to the information provided by the same companies. The precedents included spatial location of the area, meteorological conditions at the beginning and during the advance of the fire, and affected fuels. During the fire, the amount of fire fighting forces were partially estimated. The partial evaluations were accomplished in irregular time intervals, defined according to the sequence of dispatch orders from the operation center, and the quantity of mobilized resources were determined in each case.

After the fire ended, the stages of the fire fighting were repeated by using the module of fire simulation, according to the chronology of the real fire. In each case the dispatch suggestion delivered by the KITRAL system was determined and compared to the actual fire incident.

KITRAL was capable of providing partial estimates on perimeter, burned surface, and damage caused by the fire. In the real situation it was not possible to obtain this information until the fire was controlled about 45 hours after the fire began. For example, the simulator delivered similar values to the real burned surface, 427 ha compared to 410 ha respectively, which were obtained from the over-estimation margins calculated for the simulator (Castillo 1997).

The expense estimate was determined after control of the fire, which included the tariffs and personnel costs by the company that owned the resources. The rates used by KITRAL (Proyecto FONDEF FI-13, 1995) were adjusted to the same personnel values used by the company so that they would be comparable.

The differences between the actual dispatch orders and those proposals by KITRAL were compared (*table 5*). Upon examining the corresponding data to the initial dispatch, it is clear that KITRAL proposes about 30 percent more human resources. However, for the other types of resources, KITRAL provides a conservative estimate of the resources to send to fight the fire. This situation is repeated for all the registered time intervals.

In global terms, the differences observed between the actual dispatch order and those proposed by KITRAL can be explained as a result of two situations: KITRAL proposes an intense use of human resources that corresponds to the smaller cost unit within the available resources; on the other hand, the actual dispatch tends to use greater cost resources because the principal objective is to control the fire in the smallest possible time interval, which is achieved through intense use of higher combat costs and capacities for transportation of water and chemicals.

The direct fire fighting expenses were evaluated according to the chronology of the fire (*table 6*). According to the data, the actual dispatch incurred expenses that could be considered excessive, especially in the corresponding time of 15 hours from the beginning of the fire, which presents a proportion of more than 50 percent of the total expenses. The high expense occurred because the first order of the actual dispatch was not sufficient to control the fire; thus, the second order assigned a resources quota that introduced an excessively high cost within the total cost of the fire fighting.

On the other hand, KITRAL proposes an alternative that costs less for the first time interval, which calculates the quantity of resources that would be required to control the fire in future time intervals. According to this function of

Table 5-*Actual and simulated stages of personnel in fire fighting.*

Time from the beginning of the fire (hours)	Resource assignment	
	Actual stage	Simulated stage
2	61 Men 1 Cistern truck (chemicals) 1 Dozer	94 Men 1 Cistern truck (water) 1 Cistern truck (chemicals)
15	70 Men 1 Cistern truck (chemicals) 1 Airplane (water) 1 Helicopter (chemicals)	39 Men 1 Cistern truck (chemicals)
29	51 Men 1 Cistern truck (chemicals) 2 Airplanes (water) 1 Dozer	18 Men 1 Cistern truck (water) 1 Cistern truck (chemicals)
35	46 Men 2 Cistern trucks (chemicals)	66 Men 1 Cistern truck (water)
Totals	158 Men 5 Cistern trucks (chemicals) 3 Airplanes (water) 1 Helicopter (chemicals) 2 Dozers	217 Men 3 Cistern trucks (water) 3 Cistern trucks (chemicals)

Table 6-*Expenses according to the fire chronology*

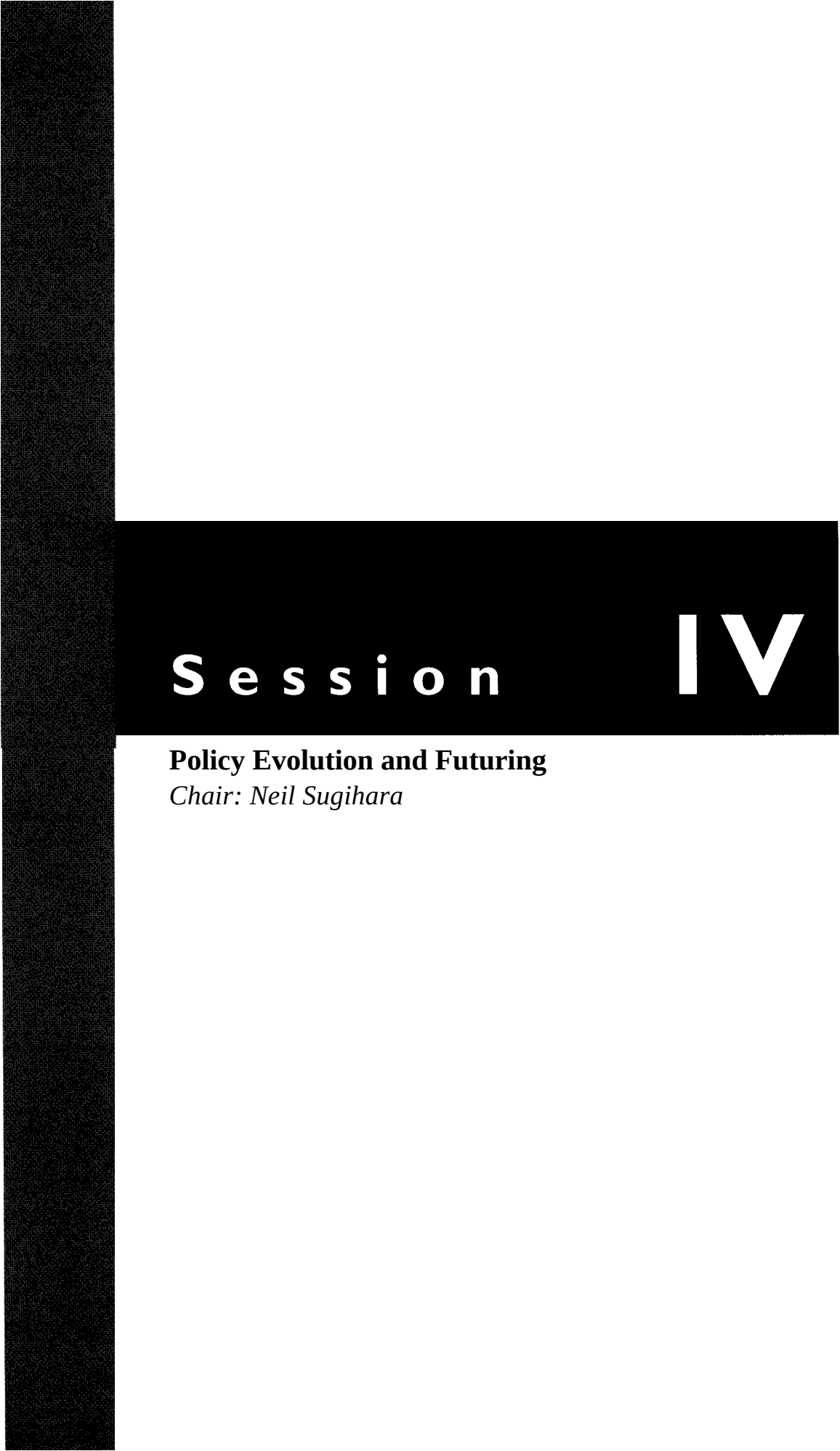
Time (hours)	Expenses (U.S.dollars)	
	Actual	KITRAL
2	4,417.0	980.4
15	54,568.9	3,179.4
29	12,319.6	5,028.9
35	4,936.4	11,363.8
Total	76,241.9	25,562.8

KITRAL, all the dispatch alternatives for the different time intervals contain a much lower cost in comparison to the actual situation.

However, the great difference between KITRAL's fire fighting costs and the actual situation indicates that a more accurate calculation will ensure a significant reduction in the expenses only by the use of a more accurate tool to evaluate and to estimate the fire behavior. This is the main impact of the system, which can reduce the operational costs significantly.

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S e s s i o n

IV

Policy Evolution and Futuring

Chair: Neil Sugihara

Strategic Holistic Integrated Planning for the Future: Fire Protection in the Urban/Rural/Wildland Interface (URWIN)¹

Glenn W. Snyder²

Abstract

Wildland fire protection in the United States has evolved from predominantly protecting natural resources values to protecting values of the urban-wildland interface. Providing fire protection in this "unnatural" ecosystem has become more complex. Wildland fire suppression costs have escalated dramatically in recent years, yet the area of wildlands is decreasing. A strategic evaluation is made of the correlation of population growth, rising wildland fire protection costs, and roles and responsibilities of fire protection providers.

Introduction

Wildfire knows no jurisdictional boundary, but fire and land-use planning is often accomplished on an ownership basis. Wildfire suppression costs and population growth in the United States are rising exponentially. Urban-wildland interface area is increasing while the area of wildlands decrease. Although the area of wildlands is declining, fire protection costs on these lands are climbing rapidly.

Society's attraction to "living in nature," as opposed to "living with nature," impacts the quality of fire protection. A shift in historical roles and responsibilities for fire protection suggests a corresponding shift of fire protection costs. Fire protection in its broadest sense includes wildland and structural types of suppression operations; fire protection also encompasses presuppression fire planning and mitigation aspects.

This paper presents an empirical, strategic assessment of some dichotomies that have developed in fire protection of the urban/ rural/ wildland interface (URWIN) over the past century; it also focuses on a sense of integrated, visionary fire protection planning for the future.

URWIN as an Ecosystem

An ecosystem is an ecological community, and its physical environment functions as a unit, whether it is "natural" (no human impacts) or "unnatural" (including the human element). Randomly implanting people and their structures on the landscape will modify the previous ecosystem. If the environment continues to function as a unit, including the human element, then another ecosystem has been created. This "unnatural" ecosystem lives in harmony until a disturbance occurs.

This ecosystem is not unlike any "natural" ecosystem, such as the wildlands. In a natural ecosystem, we can look at a disturbance as nature's method to maintain biodiversity. Wildland, in terms of ecosystems, does not necessarily equate to a "natural environment." If one considers "natural" as unaltered by humans, then little area on this planet can be classified as natural, especially considering the effects of "acid rain" or "global warming." A determining factor to be a wildland is the lack of structures. Hence, Federal public lands and other lands administratively protected from structural encroachments are envisioned as comprising the bulk of the future wildlands. If we assume that all Federal public lands in the lower 48 United States will remain as wildlands, they would comprise about 30 percent of the land area.

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On the other hand, a city is an "unnatural" ecosystem. It also functions quite well until some type of unwanted event occurs. Depending on its magnitude, a disturbance in an urban environment is a disaster. For this discussion, an urban ecosystem is a structure-dominated landscape in which any vegetation alone is incapable of carrying a fire. As in all ecosystems, seldom is a distinct delineation evident traversing from one ecosystem to another, with a fringe area where two or more ecosystems interface. As a proportion of the total land base, the urban ecosystems comprise less than 5 percent of the 48 contiguous States.

The U.S. was settled by a population that moved into the landscape and converted natural ecosystems to unnatural ones. This alteration of the landscape took place with little concern for a problem developing. It seems rural development was an acceptable and safe means of settlement. If we consider the urban and wildland ecosystems to comprise about 5 and 30 percent of the U.S., respectively, then we can assume the rural, or URWIN, ecosystem encompasses the remaining 65 percent. However, the portion of this 65 percent that can be considered "rural" is elusive. For instance, the Conservation Reserve Program and the ripened grain fields have resulted in people not only "living in nature" but also "living in agriculture." Difficulty in controlling a conflagration in various types of vegetation, wildland, range, prairie or agricultural, is highly variable. But the fact that population density is increasing in all environments raises the complexity level of providing fire protection. We will consider any non-urban and non-wildland ecosystem as part of the URWIN.

URWINization Concept

The wildland, urban, and rural ecosystems and their respective protection have progressed and evolved in relative harmony over the past 100 years. What changes, then, are making the rural development process a problematic situation? The most evident factors are overall population growth and how rural development is occurring.

Population Growth in a Fixed Land Base

The U. S. population exceeded 200 million by 1960. The population has grown to 60 million more, about a 30 percent increase in less than 50 years. Projections are that our population will be over 325 million by 2025.

Our exponential population growth is happening with little planning on how or where to accommodate the growth. Legal, economic, social, and political forces are allowed to function independently until forced to react to some event. As populations increase, the threat from natural hazards to human well being will correspondingly increase. However, the U. S. is not unique; it is a global problem.

Rural Development

Migration from urban areas to rural environments for non-subsistence purposes in the U.S. began to rapidly increase after World War II. This population shift is frequently viewed in the same light as subsistence agricultural settlement of the U.S. during the past centuries. This is not the case. The only commonality is the direction of the migration: into the wildlands.

Early habitation of the wildlands was a form of "natural ruralization." By necessity and lack of technology, if not by design, wildlands were occupied by creating open areas within the wilderness. Because transportation of building materials was limited, vegetation (trees for logs, grasses for adobe) at the construction site was used, creating "clear" areas adjacent to the building site. Consequently, providing for shelter itself promoted "defensible space."

Early ruralization usually also required some form of sustenance. Clearing land for cultivation to provide for the basic food and clothing (cotton, wool, leather, etc.) needs further promoted open space and breaking up natural fuels.

Heating was primarily by wood or other natural vegetation, which also tended to keep the open space around any structures located in the wildlands.

Early settlers and Native-Americans were aware of wildfire dangers and maintained open space around their structures by design. Generally, perhaps not by design, but again by necessity, structure locations were close to water sources. These locations would naturally be in lowlands and areas of relatively high moisture. These types of habitable sites were less flammable and less likely to be consumed during natural conflagrations.

URWIN Development

In early subsistence rural development, settlers, homesteaders, farmers, and ranchers usually removed and consumed more of the immediate fuel load than they generated in order to eke out a living. In current non-subsistence rural development, the people move to rural areas for "aesthetic" reasons, including the desire to return to the "wild," seek solitude, and escape the urbanized culture. American society has adopted technology, economics, and opportunity to create a form of "artificial ruralization," or URWINization. In general, URWINization is a phenomenon diametrically opposed to settlement, homesteading, and other "natural ruralization" processes.

Locating dwellings near a source of water is no longer a necessity. Instead, structures are frequently located in the most severe fire prone sites, such as on hillsides, steep slopes, and arid locations for the sake of "scenic views." Technology permits us to access adequate water supplies for human needs in most any location. Maintaining adequate water needs for fire protection in these adverse sites has not always been considered.

Using on-site or nearby natural materials for construction at the building site is no longer necessary, or even promoted or economical. Instead of creating a fuel break or defensible space by using on-site materials, which is usually considered an adverse impact, building materials are imported to add to the fuel load on the site. The landscape may someday become an overloaded fuels site. For some reason the perception of society is that living in the "wilds" requires the structure to be tightly engulfed within the vegetative surroundings, which is in direct contrast to early wilderness settlement. Sometimes the vegetation is incorporated as part of the structure, such as a tree growing through a deck.

Technology permits us to add significant fuels to the site by transporting in vast amounts of construction materials, mainly in the form of wood and other flammable products. In subsistence rural development, large amounts of on-site fuels were consumed for heating and cooking, significantly mitigating fire hazards in earlier times. Today, we use an insignificant amount of vegetation in our desire to maintain a "wild" atmosphere. Technology allows us to conveniently transport huge containers of explosive heating and cooking materials, locate them close to our structures, and further add to the total fuel load and fire hazard of the "wilderness" environment.

Historically fuel wood for heating has been a major factor in disposal of small-diameter woody material in URWIN areas. Strict air-pollution regulations have almost eliminated this form of wood disposal in the very areas where it is most critical.

Clearing land to provide for food and clothing is no longer required to promote fire safe environments. Instead, we now build additional structures (grocery stores and malls) in our "natural" surroundings to replace the horses, cows, goats, and sheep that all helped to keep fuel loads in check and fire breaks around structures open. Providing for consumer food and clothing only adds to the overall hazard by injecting additional fuels in the environment through additional structures to provide for the basic need of the people inhabiting the nearby structures used for shelter.

URWINization of the landscape is not only happening in the classical, forested environments. Rural areas with scattered homesteads among the open fields are becoming infused with strip and cluster developments. At the same time, for the sake of soil conservation, we are paying agricultural landowners to revert croplands to grasslands. Many of these grasslands then become a major threat for fire control since use of any crop production is limited by law.

Given that wildlands will comprise 30 percent and urbanized areas another 5 percent of the total land area, the remaining 65 percent of the land mass in the U.S. requires fire protection in some form of URWINized environment. With 60 million additional folks in the near future, not only will private "wildlands" disappear, but much of the fringe areas of the public domain will be impacted. True wildlands will exist only in the heartlands of extensive public domain lands, primitive and wilderness areas, and extensive privately reserved "natural areas."

Historical Development of Fire Protection

Historically, roles and responsibilities in fire protection evolved as needs arose and technology improved. As urban areas developed, structural protection evolved from bucket brigades to manual pumps and hoses to sophisticated fire engines. Rural fire protection has evolved around small groups cooperating and uniting for the common good. Local folks financed staff and whatever fire equipment they could afford. Again, the primary purpose was to protect their homes and basis of subsistence.

Historically, local fire fighting agencies have been, and will continue to be, the front line of fire protection, whether it is in a rural or an urban ecosystem. Wherever our society chose to settle, a structural fire protection need was created. Combined, these urban and rural firefighters have primary responsibility to provide fire protection for nearly three-fourths of the area of the U.S. Fire protection for the urban ecosystem has evolved its own techniques, equipment, and organization for fire protection. It was driven by structural protection. Rural fire protection is provided through the network of volunteer fire departments. These fire departments have evolved mainly around structural protection techniques and concepts. Until recently, rural fire protection seemed to fulfill the necessary protection needs. However, in a relatively short time, we seem to have developed an "interface problem."

Local communities, fire districts, and counties are the lead agencies to accomplish and implement fire protection programs, natural hazard mitigation efforts, promote fire-wise measures, and establish and enforce defensible space standards on non-Federal lands within their respective jurisdictions. Only in recent years have strong inroads been made to improve fire mitigation efforts.

A state's fire protection role and responsibility has varied as widely as the number of states. Responsibilities vary from having no fire suppression responsibilities to those with full-fledged, statewide fire protection organizations. Some have little direct role in suppression efforts until the fire event has gone beyond the local capabilities.

Every state has a vital role in securing, administering, managing, and coordinating fire protection suppression, support, and mitigation training and equipment. The state organization has provided the lifeline from the federal level to getting resources to the grass roots level where projects are implemented. Wildland fire protection was born mainly to protect the vast natural resources of the Federal lands from devastating wildfires, especially in the western U.S. Around the beginning of the 20th century, when Federal reserve lands (National Parks, National Forests, etc.) first were set aside, these lands were quite isolated in the midst of other wildlands. With the bulk of wildlands in Federal jurisdiction and no other means available to provide fire protection, it became a federal responsibility. Over the past century, Federal land-management agencies have taken the lead in providing for wildland fire protection on Federal as well as non-Federal lands. A highly

sophisticated wildland fire protection organization has evolved with its own techniques and equipment designed for wildland protection.

The beginning of wildland fire protection is rooted in the five Federal land-management agencies under two Departments. The Forest Service is the only land management agency in the Department of Agriculture; the Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Bureau of Indian Affairs are under the Department of Interior. The Federal Emergency Management Agency is not a land management agency; however, it is the lead agency directly under the President for all emergencies of disaster and catastrophic proportions.

The National Forest Systems branch of the Forest Service is charged with protecting and managing the National Forests and National Grasslands so they best demonstrate the sustainable multiple-use concept. The State and Private Forestry branch administers Federal technical and financial assistance to states for cooperative forestry, fire protection, forest health, and urban and community forestry programs for state and private landowners, cities, and communities through each State forestry organization. Forest and range land research comprises the third branch of the Forest Service.

As the "pool" of Federal public lands began to form at the turn of the century, the respective Federal agencies were created to administer these public trusts. Each Federal agency was congressionally mandated to administer and protect the lands under its jurisdiction in unique ways. These basic laws remain in effect today, causing each agency to develop its own unique management style and philosophy. All agencies have in common the need to protect natural resources of these wildlands from uncontrolled wildfire.

Out of this myriad of individual-agency fire protection programs was born one of the most sophisticated national organizations for wildfire suppression in the world. Although its primary role is to respond to support wildfire efforts where needed, the National Interagency Coordination Center (NICC) plays a vital role and link for assistance for any emergency, disaster, or catastrophe.

The NICC is the head of an intricate interagency national coordination and dispatching system, linked with geographical area coordination centers, which are in turn linked to locally based dispatch centers. The National Wildfire Coordinating Group (governing body of the NICC) trains and equips highly trained teams to support State and local fire organizations in fire emergencies. These too are used more frequently on non-fire emergencies in support of the Federal Emergency Management Agency responsibilities. A national fire equipment cache is also maintained at the NICC to support area, state and local fire requisitions for training and suppression.

The State of Fire Protection Today

Rural and wildland fire fighting agencies are experiencing fire events more complex. Fire occurrences on the landscape require faster initial attack, more resources, and a greater variety of resources. A fire occurrence in the URWIN usually requires a response by both wildland and structural resources until an on-site assessment and evaluation is made for potential threat to life and property.

Only in the hinterlands of the public-owned wildlands, where only protection of natural resources is at risk, can a fire event be truly a wildland fire. On the opposite side of the spectrum, pure structural fire fighting occurs only in the inner city, urban environment. Fringe areas of both wildland and urban ecosystems is an URWIN ecosystem.

With continuing population growth, the complexity of current events will elevate to a higher stage of occurrence. Each structure only adds additional fuels and risks to the URWIN ecosystem. Peripheral "wildlands" (such as urban parks, greenbelts, and urban National Forests) are subjected to higher risks as population densities continue to push along the edges of the public domain.

As these higher density URWIN areas have become more prevalent on the landscape, "simple" fires of the past now have become a high threat to life and property. Fires in the URWIN require an assorted array of wildland-structural fire fighting equipment. To minimize response times and assure proper equipment arrives at the scene, an initial response is often made by more units than necessary to ascertain sufficient resources. Until detection and dispatching systems become more sophisticated, this may be the most effective response, although perhaps not the most efficient.

URWIN fire fighting strategies carry a high price tag. If the fire fighting occurs on wildlands, although the cause is to protect structures off the wildlands, the tendency is to charge this to the wildland side of the ledger. Is it the proper role for wildland firefighters to respond to URWIN fires or do we need an elite fire fighting force with dual qualifications in both wildland and structure fires? Who should bear the costs for training, presuppression, and suppression? Who should be providing fire protection mitigation services for the URWIN ecosystem? How do we track the density of structures varying within diverse fuels of the "natural" vegetation that create a mosaic of extreme fuel conditions? These are some of the fire protection questions to consider as we enter the 21st century.

Positioning Fire Protection for the 21st Century

Federal Role and Responsibilities

In a time of crisis or major disaster, all Federal agencies may have a role or responsibility to support State and local entities as stated in the Federal Response Plan. We will focus on those agencies involved in the wildfire protection aspects.

Federal Emergency Management Agency (FEMA)

The Federal Emergency Management Agency (FEMA) provides national leadership and support to reduce the loss of life and property in major emergencies or disasters. FEMA is responsible for overall disaster management. Created by the Stafford Act of 1974, it has the leadership role for coordinating the 12 Emergency Support Functions inherent in the Federal Response Plan.

The Forest Service is one of numerous Federal agencies responsible for responding to emergencies through the FEMA. The Forest Service is responsible for addressing all wildland and structural fire fighting needs nationally in case of catastrophic/disaster conditions. It includes coordination of wildland, urban, and URWIN suppression activities. FEMA relies on the Forest Service to provide technical advice for fire suppression assistance to states when an event threatens to reach emergency/ disaster proportions.

Federal Land Management Agencies

Land management agencies play dual roles when it comes to fire protection. On the one hand, they are mandated to protect the natural resources they are chartered to administer and manage. On the other hand, by having wildland fire protection resources and expertise, they fulfill a supporting role to other fire fighting organizations of the State and local level, nationally in time of need.

Federal land-management agencies have one fire protection feature in common: they are all capable of wildland fire fighting, as opposed to structural fire fighting. This is an important distinction because, for example, bunker gear of a structural firefighter is not suitable in the wildland fire environment. Likewise, the yellow shirt with no breathing apparatus is not suitable in the hazardous smoke and heat environment of a structural fire. This often creates a dilemma in the URWIN. Federal fire-protection agencies will continue to bear the responsibility to provide for fire fighting support to assist states when their protection capability is exceeded, whether it is for wildland or URWIN.

Federal employees, as a part of the local community, can provide valuable expertise and a service if given the proper authorities to carry out non-fire duties, as well as fire protection responsibilities. The need for national resources at the local level to act as a catalyst permeates the full spectrum of emergency management. Having a workforce at the ground level is an opportunity few Federal agencies have available. However, it also brings with it certain responsibilities.

Numerous Federal land managing agencies have offices located in small rural communities. In an effort to become part of those communities, personnel deem it socially healthy, as well as expected by Federal agencies, to participate in all forms of community activities. This includes responding to requests for assistance during all types of events, incidents, and emergency.

Those same people in the field offices are responsible for management and protection of Federal lands. In most cases, those offices depend heavily on their local, county, and state neighbors to assist in activities on Federal lands. These activities include cooperative fire protection, cooperative law enforcement, hazardous materials incidents, search and rescue, etc. In society's view, this is the right thing to do, which is why most land managing agencies have good support within their local community.

Assistance given by local Federal and State employees to local communities is always in support of the local authority (county sheriff, emergency services coordinator) and only by their request. The Federal offices are not in the business, nor do they desire to be in charge, or have any sort of authority over local governments. Their authority rests entirely over the Federal lands they manage. In fire emergencies, this support is usually in the form of reciprocal or mutual aid assistance. Occasionally, fire may extend long enough to require reimbursement to a supporting party.

It is estimated that more than 90 percent of all events/ incidents, including wildfire, are handled by the capabilities of the local community. Less than 10 percent go beyond the local capability to the State or an emergency level. Fewer than 1 percent of all events go to a Presidential or FEMA disaster declaration.

It seems that Congress intended for State and local governments to prepare for local incidents, including obtaining insurance. It also seems that the Federal agencies were not intended to assist until those governments are beyond their capability to respond safely and effectively. It also appears that the law differentiates between complexities of incidents from major disasters to emergencies, both of which may have federal support.

State and Private Forestry

The State and Private Forestry (S&PF) Branch of the Forest Service connects the national fire protection program to non-federal ground through the state. The Forest Service also provides the linkages from the state to the Federal Emergency Management Agency to carry out Federal Response Plan and fire suppression assistance.

The charge of S&PF is to provide financial and technical assistance to state forestry organizations. This assistance is intended to enhance forestry practices, wood utilization, forest health, and fire protection on state and private lands in their respective states. The Cooperative Fire Protection program, as part of the S&PF, provides grants and technical assistance to support and enhance their fire protection programs; grant funds are also made available to states for organizing, training, and equipping rural fire departments. The Federal Excess Personal Property program makes federal excess equipment available on loan to State and local fire fighting agencies. This latter program has been an indispensable part of the rural fire protection program since its inception five decades ago.

Awareness of the URWIN situation was initiated over two decades ago at the national level by the Forest Service and National Fire Protection Association

(NFPA). Until then, NFPA was mainly concentrating on structural fire issues and the Federal agencies were concerned with wildland fire-prevention issues. A cooperative effort brought the structural and wildland issues to one table, with numerous conferences and awareness training sessions being developed. A niche will always remain for Federal agencies, land managing and administrative, to provide the national leadership and policies in the fire protection arena.

Opportunities exist for the Federal agencies to expand fire protection training, some of which is already being implemented. In the past, the National Wildfire Coordinating Group focussed heavily on the wildland fire suppression aspects of training. The Fire Administration, as part of FEMA, and the NFPA have led the cause for structural protection. Both wildland and structural training of these agencies has been mainly carried out by "on-site" training approaches. This is effective, but also costly. In some cases, it is necessary to have hands-on and on-site training, but not in all cases. Members of Volunteer Fire Departments (VFDs), especially, have neither time nor money to travel and attend distant training sessions. Yet, these folks are the backbone of the URWIN fire protection program. Technology is available to promote awareness and conduct training for fire protection far more efficiently and effectively through comprehensive distant-learning techniques. This type of effort can best be coordinated from the national level to assure standardization of training to meet national commitments.

Large-scale assessments are viewed at least at a river-basin watershed level. With the end of the "cold war" came relief of exceptionally tight security on satellite and other remote-sensing data. Greater efforts need to be made to use improved information in strategic-level planning at the national and state levels. Particularly at the national scale, integrated assessments of risk and hazards of all natural events should be accelerated. Fire protection assessments are envisioned as only one element in the strategic planning for all national disasters. The risk, hazard and value concept of the assessment process is as applicable to floods, tornadoes, hurricanes, earthquakes, blizzards, and volcanoes as it is to fire protection.

FEMA has the lead role to play in coordinating this type of effort. Federal land-management agencies have made inroads in large-scale assessments, as have some states. To be productive and effective in the future, national standards need to be developed to avoid a quiltwork pattern as lower level assessments are aggregated from the ground. FEMA, as the keeper of the Federal Response Plan and chief coordinator for disasters, could provide the basic framework for assessment processes and make remote-sensing and mapping data available to the other Plan participants. This would include state partners involved in fire protection and other emergency operations.

State Role and Responsibilities

Each state of the union has its own constitutional mandates. The role each state will or should play in providing fire protection within and outside its jurisdictional area will vary by each of the individual states. This does not preclude developing some basic roles and responsibilities of all states. An essential role for all states is to provide the avenue to implement congressional intent of Federal grants through the administrative organizations within each state. The National Association of State Foresters is a vital link to the national level for forming national policy and direction for fire protection.

Although we generally think of controlling land-use processes through local planning and enforcement agencies, the framework within which these agencies operate is dictated by State government. State government policies on industry, social welfare, etc. will affect the immigration and emigration of population and where it will take place. State culture and attitudes are formed on the basis of the governing philosophy. State governors and lawmakers dictate the roles their

administrative agencies will carry out in conjunction with URWIN fire protection. Major progress was made in helping define a state's role and responsibility in the URWIN by the policy development of the Western Governors Association.

A state's role in awareness and training is envisioned as more specific to the unique physiological, sociological, and climatic conditions prevalent within each state. URWIN fire protection awareness and training has tended to focus on the western forested states. Recent situations on Long Island, New York, and other eastern areas have manifested the needs for all states to have an awareness of the URWIN. Few states, if any, are expected to experience large-scale emigration. On the contrary, states can expect their URWIN conditions to intensify over time as populations shift and increase. Mobility of the workforce means awareness is a continuous need.

State involvement in fire protection training will vary considerably by state, depending on land ownership patterns. Some states have extensive holdings in public ownership while others have none. In any case, each state must provide the leadership and make available the necessary training resources to maintain adequate fire protection in the URWIN.

No state can be expected to meet all its fire protection needs all the time. It becomes incumbent for those states receiving Federal grants for fire protection to have fire fighting resources from that state be available for national or interstate fire emergencies. Internally, the inherent responsibility of every state is that it provide for the safety and fire protection of all citizens by supporting and training local fire fighting resources.

Fire is usually considered negatively, especially in the URWIN. Some of this perception stems from devastating wildland fires and fire prevention messages. Similar to a state's awareness and training responsibilities, it is paramount that the value of fire use through public education is promoted to a greater degree. It has been demonstrated that fire can be safely and ecologically applied in the URWIN ecosystem. Smoke management restrictions are often unique to each state; consequently, State and Federal fire protection and air quality agencies need to cooperate to avoid negative impacts of fire applications in the URWIN. Proper use of fire can help alleviate the disposal problem often encountered with small-diameter materials when performing fire-wise projects.

In any of the large-scale assessment processes, the resolution of the scale of assessment will dictate the strategic value. The statewide scale can be viewed as a mid-level strategic planning effort. By developing an aggregate of hazards, risks, and values, priority focal points for protection mitigation or suppression efforts can be identified. By overlaying a jurisdictional layer, areas are further delineated by responsibility. By introducing the dynamics of climate and weather for given fire behavior and geographical conditions, fire fighting resources can be pre-positioned to high fire danger areas, and requests for FEMA assistance can be facilitated. State forestry organizations or Offices of Emergency Management can alert and assist local entities in preparation for an event that may become a potential disaster.

An assessment process will facilitate the integration and coordination of other state emergency agencies and state forestry fire protection entities. Each state program area would continue to carry out their mandated responsibilities, but efficiency could be gained by integrating planning in a holistic, all-disaster perspective.

Comprehensive assessments can help focus risk/hazard mitigation efforts, identify geographical locations requiring fire protection priority, and evaluate areas for large-scale natural fire re-introduction efforts. An assessment of other types of occurrences, such as floods, earthquakes, etc. can be made. Once high-risk areas are determined for each type of occurrence, these risk overlays can be compiled to determine whether multiple risks and hazards exist on any given location of the landscape.

Community-based Fire Protection

Implementation of programs occurs on the ground. What actions are taken to provide for pre-incident preparations, mitigation, or incident response and recovery is dependent on the local elements. Funding and assistance provided by upper echelon entities are only effective if properly applied at the community level.

Land Use Planning and Enforcement

State and national planning and assessments must be capable of accommodating local planning efforts and situations. Project level planning has to have the capability of being aggregated upward. In other words, battle plans need to fit within the overall scheme of the fire-protection war effort. Local land-use and zoning regulations dictate the URWIN landscape. County commissioners, fire district directorships, and community leaders, all share the responsibility for determining priorities and shaping their local landscapes.

Fire Use and Education

Local educational institutions, homeowner associations, and environmental groups, have an important role in informing the public of the value of defensible space, fire-wise mitigation measures, and fire prevention. Local Federal and State employees and fire protection resources need to be incorporated into community planning. They need to be empowered to support "legally" other local emergency situations and mitigation efforts, as well as fire protection responsibilities.

Fire Protection "Assessments"

In contrast to landscape assessment planning or project-level planning, protection assessments are construed as "taxes." A basic premise is that where there are people, there should be a tax base. If a tax base exists, then it follows that a source of funding local protection infrastructure also exists. Local emphasis on levying assessments should not preclude continued state and Federal assistance for fire mitigation as well as protection.

Another basic premise is that Federal and State agencies are in a support role to the local level. With this in mind, logic would indicate that the local populace would be willing to pay for providing local fire protection needs. Only when an event exceeds the capability of the local infrastructure and only at the request of the local people will protection assistance from the state and federal level come into play. This assumes local state and federal folks are already committed as part of the local emergency response organization.

In an all-risk-planning concept, wildfire would be viewed no differently than other natural disturbance processes. Mitigation efforts are required to minimize human suffering and property loss when a disturbance event occurs. Seeking ways to avoid duplication of effort and redundancy of operations both internally and externally among all agencies would be progress toward saving taxpayer dollars at all levels.

Reviewing recent emergencies and disaster situations indicates society has a false expectation of the capabilities of emergency management responders, especially in catastrophic cases, such as hurricanes and earthquakes. People seem to expect the Calvary to arrive immediately after a destructive event. Regardless of the expertise and efforts of an emergency agency, if no infrastructure remains after a disaster, outside assistance may not be forthcoming for the initial 24-48 hours. To prevent false expectations, a locally based education program is paramount.

Most communities already have some type of emergency response system in place through Volunteer Fire Departments, Ambulance Services, and law enforcement units. What may be lacking is an organizational/communications structure for coping with all events or incident management.

Summary

Technology, education and awareness of fire use and protection, and sorting through the changing roles and responsibilities of all the stake-holders in the URWIN will permit "living with nature" in a relatively low-risk, catastrophic-safe URWIN ecosystem. URWINization has created an ecosystem in its own right; it may not be in harmonic balance when disturbed, but it is an ecosystem, nonetheless. Educating the public, overcoming traditionalism in the fire organization, and revamping fire training approaches are major areas of opportunity to accelerate protection mitigation efforts and apply fire use in the URWIN.

Intermeshing FEMA disaster/ emergency overhead team components, where feasible, with compatible fire incident overhead team positions may help achieve a better understanding of the function and role each agency. The intent is to develop a bridge to more efficient and cost effective disaster and emergency response teams to deal with all "catastrophic events."

The URWIN will not significantly change in area over the next half century. Public lands will remain the bastions of the wildlands, and the remaining privately held "wildlands" and URWIN ecosystem will become more densely structured, with some of the current URWIN ecosystem converted to an urban environment. URWIN fire protection costs can not be expected to decrease or level off in the future. As long as Federal wildland fire fighting agencies continue to absorb protection and suppression costs for indirect structure protection in the name of wildland fire protection, we can only expect a corresponding escalation in wildland protection cost. That increased cost will be born by the federal taxpayer. However, one could hope that long-term goals would prevail to give all taxpayers a fair chance.

As federal taxpayers, what portion of the total fire protection bill should be assigned to covering the presuppression and suppression costs associated with private lands? As state taxpayers, what fire protection costs are to be picked up on non-state lands in the interest of protecting private lands. As local citizens and private landowners, whether privately employed or local, State or Federal government employees, how much are we willing to pay and what are we willing to do to provide for a fire-safe URWIN ecosystem?

Mechanisms are already in place to shift the fire protection costs to whatever direction we choose. Responsibility for implementation of any program on the ground ultimately lies with the local citizenry. Transition from a federally funded basis to a state and local funded groundwork will surely be a time-consuming process. Basic elements are in place at all governmental levels for this transition to occur. All we need is the political will, fortitude, and foresight to make it happen.

The Red Books of Prevention and Coordination: A General Analysis of Forest Fire Management Policies in Spain¹

Ricardo Vélez²

Abstract

A steadily increasing number of fires and the high intensity of fire seasons every 4 to 5 years have marked the last two decades in Spain. A generalized first attack system supported by aircraft and new technologies has achieved a main goal: more than 70 percent of fires burn less than 1 ha. Nevertheless, fuel accumulations on large areas because of rural land abandonment have increased the risk of large fires by lightning. This same socioeconomic phenomenon increases the risk of large fires by traditional agricultural and bush burning. In 1995 budgets devoted to fire management attained an average, in U.S. dollars, of \$5/ha for prevention and \$10/ha for suppression. The protected surface is nearly 25 million ha, including forest, brushlands, and grasslands in the mountains. However, suppression resources are difficult to maintain because of declining public budgets under the present economic policies in Europe. A deep analysis of the situation has been performed by the Forest Fire Committee (FFC), the Spanish equivalent to a National Forest Fire Coordinating Group. Two Red Books on Prevention and Suppression have been approved in 1997. Their approaches to implement new policies are summarized in this paper.

The Red Book of Prevention

The description of the current forest fire situation in Spain is documented in the National Forest Fire Database started in 1968, when the forest fire law was approved. The Red Book includes a series of tables and graphs for every region in Spain. The number of fires is increasing in the northwestern regions and shows stability at the Mediterranean areas, although it is not decreasing in anywhere.

Fire Causes

Lightning fires are less than 10 percent every year, but they are frequently at the origin of the largest burned surfaces. Light fuel accumulations (grasses and brushes) are also at the origin of most fires. A classification of fire causes can be established as:

- High probability motives in all regions:
 - Agriculture and grazing land burning.
 - Private revenge.
- Probable motives identified in certain localized regions:
 - Conflicts related to game hunting rights. - Conflicts related to wildland ownership.
 - Conflicts related to forest policy: reforestations in communal areas; restrictions of local use in protected areas (national and natural parks).
 - Fires set to chase off wild animals (wild boars, wolves).
 - Fires set to create jobs in fire fighting or in reforestations.
 - Rubbish burning at the tourist areas where the urbanization process is expanding.

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- Low probability motives:
 - Fires set to make the price of timber drop.
 - Fires set for political reasons.

Problems and Recommendations

A questionnaire was circulated by the Forest Fire Committee (FFC) to collect views from all the people concerned by forest protection (central and regional administrations, forest owners, farmers organizations, forest companies, journalists, police, etc). The analysis of the answers led to several lists with 33 main problems and recommendations. These can be summarized as:

Problems	Recommendations
• Including fires in the database	Strict use of the legal definition of forest fire.
• Investigation of causes	Training courses on investigation techniques. Permanent crews devoted to investigation.
• Forecasting fire danger	Coordination of the weather station networks. Forecasting lightning storms. Spreading forecasts on drought dry storms, and dry winds.
• Fuel accumulations at the wildlands	Promoting and supporting economic programs of preventive silviculture. Developing programs of prescribed burning. Coordinating crops and livestock, European Union subsidies, and controlled burning. A fire would cancel the subsidy. Coordinating reforestation of former agricultural land and preventive silviculture. Promoting self protection at the wildland /urban interface. Promoting research on fuel management and fire effects.
• Dissuasion	Promoting coordinated programs of patrolling between the Forest Services and the different police. Promoting associations of voluntary local people for patrolling, distributing vehicles and other equipment for that purpose. Enforcing rules on traffic on forest roads and on garbage burning.

•Sensitization

Enlarging the current propaganda campaigns for urban people, farmers, and school children.

Spreading standardized information on forest fires to the media.

Periodical inquiries of the public opinion on forest fire management.

Fire causes and the related prevention programs are defined according to the recommendations of The Red Book of Prevention (*fig. 1*).

The Red Book of Coordination

The analysis of the performance of the suppression system is also documented by the National Forest Fires Database. The Red Book includes a series of tables and graphs for Spain and for every autonomous region. The average surface per fire shows a slight decreasing trend. Although the total number of small fires (< 1 ha) is increasing, the number of fires over 1 ha is stable or decreasing in several regions. The average fire in the northwestern regions is around 5 ha; in the Mediterranean regions, it is over 10 ha. Nevertheless, the big fires over 500 ha (0.3 percent of the total) burned 45 percent of the total burned surface. In 1994, 79

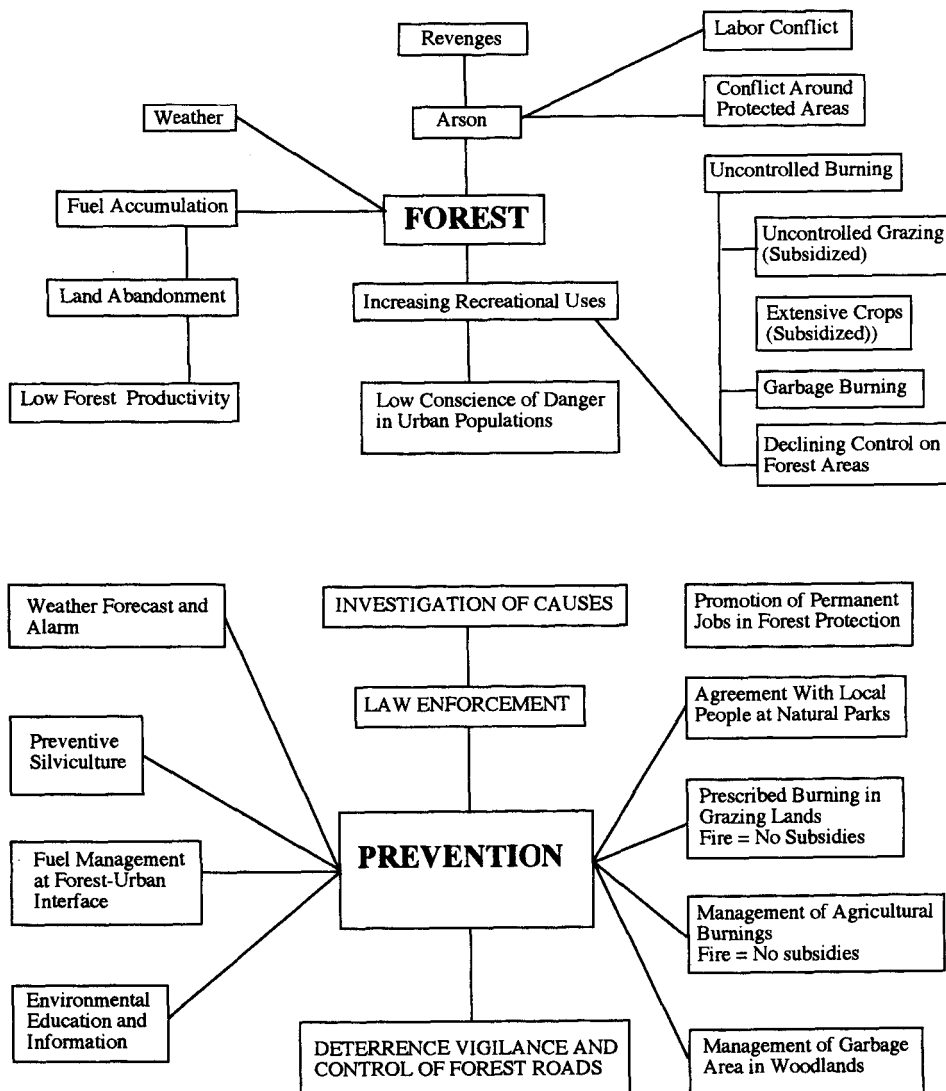


Figure 1
Fire causes and prevention policies.

out of 20,000 fires burned 80 percent of the total burned surface. Dry winds blowing from the continental areas create high danger in the coastal regions. This problem is less serious at the inland regions.

The lookout network is still the basic detection system, although mobile patrolling has detected an increasing share of the number of fires. This system is working only during the summer fire season (June to October). During the other months, the cooperation of local people is increasing.

Aircraft and infrared sensors are of limited use for detection, but very interesting for observation and transmission of images to the operation centers. By the middle of the 1980's the introduction of the helicopters brought a high reduction in the delay of first attack. Currently, that time is less than 15 minutes in nearly 50 percent of fires. Direct attack is the technique in 85 to 95 percent of fires. Fire lines opened by hand tools and dozers are typical of extended attack. Counter fire is used in very few cases because of responsibilities and lack of training. The 1990's have seen first expansion and later stability in the number of aircraft involved in fire fighting. The state fleet of 20 Canadair is the core of this use.

Agricultural aircraft are still in use in many places, but the big increase has been in the use of helicopters. Crew transportation is their main role, but dropping water and foam is also an important activity. Aircrafts are present in 15 percent of fires.

Problems and Recommendations

The same procedure described for the Red Book of Prevention was followed for Coordination. Several lists of 30 main problems and recommendations were identified for a general suppression event (*figs. 2, 3*).

Problems

Function: General planning limited by the annual budgets.

Function: Coordinator procedures of and rules non-homogeneous at provincial, regional, and central levels because of the structural diversity of the regions.

Function: Director of a fire. Lack of a comprehensive legal definition of this job.

Recommendations

The need for multi-year plans, adapted according to the budget allocated every year.

Coordination between the regional and the central plans.

Reports on large fires and on accidents with victims: A systematic input for planning.

Establishing a common Handbook Coordination for central support to the regions for border operations.

Designing a model Operations Center, according to the present technologies.

Auditing the regional communications systems to improve their compatibility.

Standardizing the information flow to the media.

Updating the legislation supporting a certification system based on training courses and real experience.

Documenting all decisions by written operations plans.

Covering responsibilities by a general insurance.

Function: Planning of operations.
Lack of written operation plans,
including forecasts of fire behavior.
Lack of cost control mainly
in large fires.

Excessive use of direct attack
with water in all circumstances.
Structural fire services, with
responsibilities also in forest fires,
are never to counterfire,
even in large fires.

Increasing the number of mobile
units for meteorological and
communication support that receive
images from the air observation aircraft.

Establishing a common Handbook
for Operations Planning.

Analysis of cost effectiveness
according to previous rules to verify
resources.

FIRST ATTACK

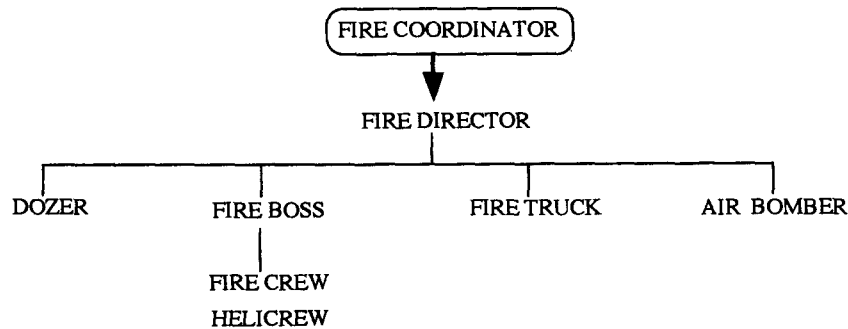


Figure 2

Schemes for attack.

EXTENDED ATTACK

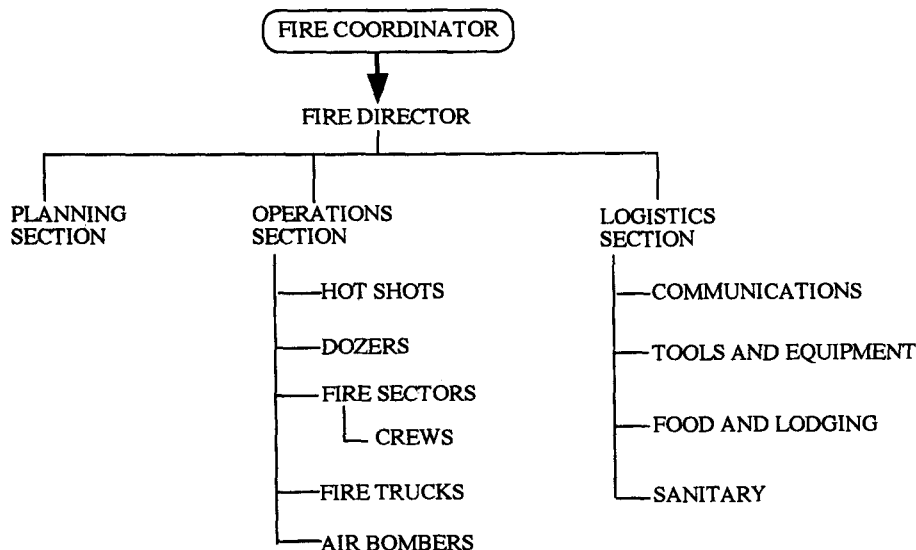
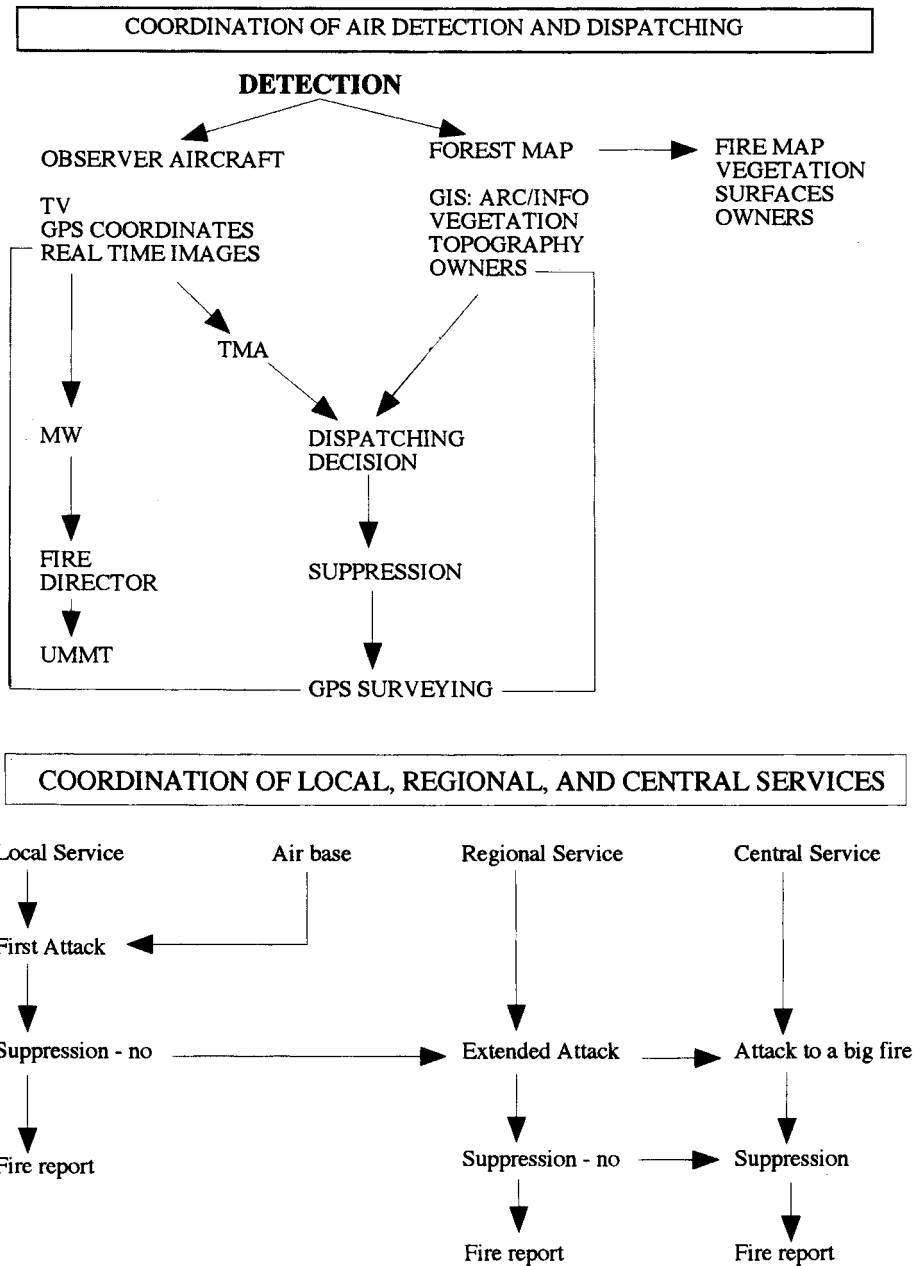


Figure 3
Schemes of coordination.



Function: Operations.
Multiplicity of systems, making
difficult the Integration of resources

Standardizing rules for personnel
selection and training .

Establishing a certification system
from different agencies.
for all levels of responsibility.

Standardizing the equipment for
personal protection.

Standardizing work shifts in a fire,
and compensating extra time of
suppression with vacation time.

Coordinating suppression jobs
(summer) and silviculture jobs
(winter) to retain personnel.
Following written operations plans.

Designating air coordinators when
more than two aircraft are
operating.

Function: Logistics.
Difficulties in large fires when
there are resources from several
regions.

Establishing rules for logistics,
taking into account the arrival of
resources from different agencies or
places.

Giving sanitary training to one person
per brigade.

Conclusion

Forest fire services in Spain have attained a good level of effectiveness with a high proportion of professionalism. However, there are several main difficulties to keep pace with the fire problem:

- Increasing fuel accumulations because of rural land abandonment.
- A high number of simultaneous fires in certain regions.
- Diversity of the regional administrations that have the responsibility for first attack.
- Coordination at the large fires.

The Red Books of Prevention and Coordination are a common exercise to look for new ways to improve the quality of the suppression services and to design stronger policies for prevention.

Economic Principles of Wildland Fire Management Policy¹

Hayley Hesselin,² Douglas B. Rideout³

Abstract

Evolving wildfire management policies are aimed at more comprehensive treatments of current wildland fire management problems. Key policies are identified that affect wildfire and fuels management. Policies are discussed in the context of institutional factors such as interagency cooperation and the growing number of regulations and laws. Key economic principles, such as the Coase Theorem, are developed in the context of contemporary policies and institutions. Economic principles of specific management situations are discussed, including smoke emissions, the wildland-urban interface, suppression policies, and the use of prescribed fire. Policy formation as it applies to a dynamic society with implications for emerging issues in the new millennium are also addressed.

Introduction

Over the past several decades, the forest fire suppression policy has altered natural fire regimes in many fire dependent ecosystems, resulting in ecological change and increased probabilities of wildfire activity (Donaghue and Johnson 1975, Mutch 1994) as well as social and political concern. It is widely acknowledged that in the absence of wildfire, vegetative changes have resulted in fuel loads that far exceed historic levels and pose serious threat to forest and cultural resources if ignited (Arno and Brown 1991). In addition, continuing urbanization is contributing to increased fire danger in the wildland-urban interface, further complicating fire management and adding to the already limited physical and financial resources.

Although there has been a shift toward reintroducing fire to reduce fuel loads and to restore natural ecosystem processes, fire managers must also consider social pressure to protect lives and natural and cultural resources. Primary concerns include public safety, risk, inconvenience from smoke, reduced air quality, decreased esthetics, and fiscal responsibility. The Federal Wildland Fire Policy of 1995 addresses several key areas of fire management and recognizes the need for activities based on science and sound ecological and economic principles (USDI / USDA 1995). Although fire policy and economic theory are often at odds, economic principles are important to evaluate the effectiveness of such Federal policy. Given fire management objectives and widespread concern regarding wildfire, it is important to policy-makers, land managers, and the public to assess wildland fire policy from an economic perspective.

This paper provides a discussion of economic principles pertaining to the Federal Wildland Fire Policy of 1995. We begin by reviewing issues among the five topic areas. Within each topic area we discuss key fire management policies and the economic implications of such policies. Finally, we discuss policy formation and emerging issues that will be important to fire managers, the public, and policy makers in the next millennium.

Federal Wildland Fire Policy 1995

The Federal Wildland Fire Policy was revised in 1995 in response to changing social and ecological factors to emphasize the need to incorporate fire into land management actions rather than the traditional approach of total fire suppression.

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The stated purpose of the 1995 Federal Wildland Fire Policy is to reduce the threat of catastrophic wildland fire through proactive goals and actions. The document outlines 13 broad wildland fire policies that pertain to 5 topic areas (USDI /USDA 1995). We will focus on the five topic areas and discuss key fire policies that shape fire management. The five topic areas include the role of wildland fire in resource management, use of wildland fire, preparedness and suppression, wildland urban interface protection, and coordinated program management.

The Role of Wildland Fire in Resource Management

Decades of successful fire suppression has significantly altered landscapes in many fire-dependent ecosystems resulting in increased fuel loads and altered fuel arrangements, as well as changes in vegetative structure and composition. Given such changes, wildfires are more likely to ignite, burn with greater intensity, and spread more rapidly causing a greater level of financial and ecological damage than in the past. The past suppression policy has also resulted in mean fire intervals that far exceed natural levels, exchanging past and current damage for increased future damage. The forest fire policy recognizes that fire is an integral part of some ecosystems and that it will be necessary, where feasible, to reintroduce fire and reduce mean fire intervals. The 1995 policy states that fire will be integrated as an essential ecosystem process through planning, the use of prescribed fire, and education (USDI/USDA 1995). All areas with burnable vegetation will be required to formulate fire management plans and fire prescriptions in the case of both human and natural ignitions.

Although the ecological role of fire is important, reintroducing fire is a contentious issue that must be addressed both socially and economically. First, although fire is a necessary and integral part of the ecosystem, public acceptance may prove difficult to achieve and significantly add to the cost of fire management. Society has been deeply ingrained over the past several decades with the idea that wildfires are not desirable and should be extinguished at all costs. The USDA Forest Service's successful Smokey the Bear campaign is testament to this fact. Further, smoke emissions and reduced esthetics as a result of charred trees add to social unacceptability of reintroducing fire into the ecosystem.

The success of the fire policy will strongly depend on education and public acceptance. Although prescribed fire often negatively impacts esthetics, results from catastrophic wildfires may be longer lasting and less desirable. To effectively obtain public acceptance, the long-run costs and benefits of both wild and prescribed fires should be identified and evaluated so the public can be made aware of trade-offs. Manfredo and others (1990) provide evidence that education is an effective tool in achieving social support for controversial Federal policies. They conducted a survey to determine the public's state of cognition regarding prescribed fire policies. Although they found the public to be polarized in their support of various fire policies, they suggest that education and knowledge tend to increase the support for prescribed burning programs. They conclude that social and economic support is critical and necessary before such programs can be successfully implemented.

Although there is biological and ecological support for reintroducing fire, there are economic issues to be considered. Fire managers need to quantify the physical relationships between fire management activities and long-term ecological changes. Also, it will be necessary to evaluate the long-term economic effects of such relationships, including expected changes in expenditures, resource and property damage, and an assessment of market and non-market benefits. With respect to physical effects, tools to evaluate the frequency and intensity of prescribed fire programs required to affect long-term fuel reductions, changes in vegetative composition, and effects on suppression needs, should be further developed. If current fire programming is temporally and geographically

insufficient, it may not generate substantive ecosystem changes necessary for effective long-term fuel reduction and hazard abatement.

There is very little economic research on the effects of reintroducing fire, which may be a result of the scarcity and inconsistency of data. Economic studies have typically focused on estimating cost per acre (González-Cabán and McKetta 1986, Jackson and others 1988, Rideout and Omi 1995, Wood 1988) or fire management efficiency (Bratten 1982, González-Cabán and others 1986, Mills and Bratten 1982, Mills and Bratten 1988). Given that the fire suppression policy resulted in ecosystem changes that occurred over several decades, the policy to reintroduce fire will likely take several decades to reverse such changes.

Use of Fire

The use of prescribed burning to achieve management objectives is becoming more prevalent and is recognized as ecologically beneficial for fire-dependent ecosystems. There has been much research to support prescribed burning as a management tool to reduce hazardous fuels and to restore ecosystem functions (Arno and Brown 1991, Donaghue and Johnson 1975, Omi 1989, Williams and others 1993). To effectively use prescribed fire as a means to achieve such objectives, it is appropriate, in addition to obtaining social acceptance, to evaluate trade-offs and to determine whether treatments are cost-effective over the long term. Similarly, it will be important to determine the temporal and geographical scope necessary to be effective.

The cost of prescribed burning is influenced by biophysical, economic and social factors, such as burn characteristics, number of acres burned, potential damage from escape, and related social costs (Cleaves and Brodie 1990), all of which are important for planning and decision making. Increasingly, however, laws and regulations are adding to the cost of prescribed burning (Cleaves and Haines 1995). Specifically, such increases are attributed to increased regulation and permit requirements, increasing liability risk and insurance costs, and finally, opportunity costs where the agency chooses to forgo prescribed burning in favor of other fuels management techniques. Such actions may lead to a decline in the number of acres burned that may precipitate a greater threat of wildfire in the future, and consequently, higher levels of damage and social costs.

Given that costs are increasing, it will become increasingly difficult to burn an effective number of acres over time. For prescribed burning to effectively reduce hazards associated with wildfires, it has been suggested that the number of acres burned annually should be increased tenfold (Bell and others 1995). Not only will this increase the total cost of burning, it will likely increase emissions and public opposition. Smoke is an important issue with respect to the use of prescribed fire. Although the public often rejects prescribed burning because of smoke emissions and perceived risk, prescribed burning may be a cheaper alternative than increased smoke levels resulting from catastrophic wildfires. Similarly, prescribed fires will reduce the risk of catastrophic wildfire, thereby reducing the risk to society over the long term. For Federal policy to be effective, managers will have to evaluate the future costs of trade-offs between prescribed and wildfire, and the effectiveness of suppression versus presuppression, both socially and financially, and work closely with constituents to achieve the necessary support.

Finally, cooperation between agencies is recognized as being crucial to achieving long-term objectives. Fire management is conducted within administrative boundaries often without regard for ecosystem needs and landscape patterns. To achieve results on the ground, agencies will have to consider ecosystem boundaries rather than administrative boundaries. According to the Coase theorem (Coase 1960), to efficiently use prescribed fire, managers across agencies could collaborate to achieve the least cost solution and obtain economies of scale. Similarly, through cooperative agreements, prescribed

burns planned at the landscape level may also provide the required necessary geographical scope to be effective.

Preparedness and Suppression

Because of the successful suppression policy of the past, Federal agencies' abilities to plan and suppress fires have been negatively impacted---firefighter safety has been compromised and resources are increasingly overextended (USDI/USDA 1995). Three closely related policies designed to address these issues will be important for effective wildfire management: planning and values to be protected, protection priorities, and adequate protection capabilities. First, given the goal to suppress fires at minimum total cost, values to be protected will be a key component in determining strategies for large-fire suppression. Values will include human life, and relative values of property and natural/ cultural resources. From an economic perspective, the value of human life can be measured and is not infinite, contrary to the prevailing social belief. Likewise, the value of natural resources can also be measured where markets exist and estimates of prices are obtainable. However, measuring non-market values presents a problem. Existence, option, bequest, and intrinsic values represent intangible benefits that are difficult and sometimes impossible to measure. Methods to estimate such values are well developed in the scientific literature yet are not easily obtainable (Loomis 1993). Such values will likely be associated with cultural resources and ecosystem function and will likely present significant problems when trying to quantify and include them in management plans.

The beneficial effects of fire are recognized theoretically as well as within the policy, yet in the past these have not consistently been considered as part of the calculus in determining the net costs and damages resulting from wildfires. The current policy suggests that to be consistent with overall policy objectives such benefits should be included. Although this component is an important element to effective resource allocation, benefits from wildfires are also typically difficult to estimate, particularly long-term ecological benefits. To date there is a lack of research that quantifies the benefits from both wildland and prescribed fires. Furthermore, the economic values of such ecological effects are equally difficult to estimate without the production function relationships mentioned previously. Without such information, inclusion of both beneficial effects and non-market values will be impossible, necessitating further economic research to effectively implement this policy.

The second policy relating to preparedness and suppression prioritizes the values to be protected. Human life remains the first priority, while values relating to property and cultural/ natural resources are considered equally as a second priority. Criteria to evaluate resources include environmental, commodity, social, economic, political, public health and other values (USDI / USDA 1995). However, many such values are difficult to quantify. Without such estimates, it will be impossible to establish priorities. Furthermore, objectives may be diametrically opposed in some instances. For example, political priorities often focus on providing outcomes for small groups of constituents regardless of cost efficiency, whereas economic objectives focus on achieving efficient solutions for society as a whole. Similarly, there may be conflict between commodity and environmental values that leads to conflict in establishing protection priorities. Before priorities can be established, it will be necessary to establish a framework that can be used to evaluate the priorities for the criteria in addition to the values to be protected. Again, this will require further economic research in the area of non-market valuation, particularly with respect to cultural resources and resources that do not provide market-based products.

Finally, preparedness and suppression pertains to resource availability and positioning, including employee expertise and availability. To better achieve suppression effectiveness, fire management plans will focus on maintaining

sufficient fire suppression and support requirements and pay particular attention to the proximity of resources. However, criteria to evaluate "sufficiency" is not listed and may be difficult to quantify particularly in the event of changing ecosystem functions as a result of fire reintroduction. Because funds are becoming increasingly limited, achieving efficiency is important. However, a broader approach should be taken when evaluating suppression needs and capabilities. Currently, the budget for emergency fire fighting funds (FFF) comes from an unlimited source (USDI/USDA 1993), whereas the budget for annual programming is limited. The unlimited suppression funding increases total fire management costs and creates disincentives to invest in fire management activities such as prescribed burning. To promote efficiency, research should examine the effects of presuppression activities in reducing future suppression costs. Without budget restructuring, unlimited funding will continue to increase total fire management costs while investments in prescribed burning remain significantly under-funded.

Wildland-Urban Interface Protection

The number of people living in and near National Forests is increasing. This area, known as the wildland-urban interface has been growing significantly over the past decade and is becoming one of the most controversial areas for fire managers to administer (Cortner and others 1990b). Increased fuels and fire hazard have increased the need for fire protection and have greatly added to fire management costs in addition to compromising the safety of firefighters.

Although private land does not fall under a Federal protection mandate, many residents feel that it is the Federal agencies' responsibility to provide fire management resources. Furthermore, residents are often not fully cognitive of the risk in such areas, and therefore, do not take appropriate steps to reduce hazards (Beebe and Omi 1993). They note that the media can greatly influence public perception regarding wildfire and prescribed fire. In some cases, media coverage conveys the importance of fire management in areas of risk, but in others, such coverage leads to widespread opposition of policies that use prescribed fire to reduce the risk of future catastrophic fire. They also support the notion that education and public participation are key factors in implementing successful prescribed fire programs. Where the public is informed and plays an active part in the decision making process, the use of prescribed fire may be more readily accepted, thereby reducing social and managerial costs.

Federal monies are available through the Federal Emergency Management Agency (FEMA), as well as private insurance, which reduces individual responsibility for fire management protection and risk reduction. If the cost of fire protection and hazard reduction is not borne by the resident, there is no incentive to take action individually, further increasing the pressure for Federal protection. Furthermore, without a full assessment of risk and hazard, individuals living in the urban interface cannot make informed decisions.

Another complicating factor regarding the wildland urban interface results from the lack of a clear definition with respect to the Federal role in protection. Although Federal policy does not include protection and management of private lands, the public often expects protection and generally opposes the withdrawal of forces from the wildland urban interface (USDI/USDA 1995). Currently, Federal agencies are limited to providing emergency assistance, training, and cooperation in prevention efforts. However, expectations that the Federal government will provide such services often results in social pressure, over-extension of fire fighting forces, and inefficiency. Furthermore, fire protection is inequitable from a societal perspective because tax dollars are used to protect select individuals who choose to live in the wildland urban interface. Solutions to achieve more efficient fire protection on Federal lands and to alleviate the social burden include billing individuals for suppression expenses and other fire

management services such as prescribed burning and fuels reduction. Similarly, insurance rates could be adjusted to capture the true cost of fire management resulting in a user pay system.

Coordinated Program Management

The organizational climate within Federal agencies has not been conducive to effective fire management in the past. Several criticisms include the lack of consistency in evaluating accountability, program efficiency, organization, legal and policy analysis, responsibilities and liabilities, as well as data management and weather support (USDI/USDA 1995). Policies to address such issues will focus on improving accountability and agency support as well as more emphasis on improving efficiency, particularly with respect to large fire suppression efforts. Finally, more importance will be given to implementing uniform policies within each Federal agency to provide employee support and increase responsibility at the administrative levels.

Although such improvements are important and will greatly enhance organizational efficiency, the policy overlooks an important issue. Risk is an inherent factor for both wildland and prescribed fire and has the potential to adversely affect economic viability as well as social acceptability and potential agency support. Risk refers to the probability of escape resulting in financial and ecological loss and the possibility that objectives will not be achieved. Alternative management scenarios generate different degrees of risk and ultimately a different set of economic outcomes (Cleaves and Brodie 1990).

Fire managers frequently have the discretion to make decisions based on their own expert judgment with respect to fire management and the extent of the risks undertaken. Typically, individual managers demonstrate higher levels of risk aversion than do agencies, primarily because individual managers are held responsible for problems that may occur, often resulting in higher operational costs. Blattenberger and others (1994) found that regardless of the approach to objectively include estimates of risk in fire management models, decisions are ultimately weighted by the decision maker, and acted upon according to individual levels of risk aversion. Similarly, Cortner and others (1990a) found that safety and resources at risk are two of the greatest influences on fire decisions, followed by public opinion, agency policy versus local and regional directives, reliability of information, and ability to maintain judgmental discretion.

Although research objectively identifies risk by using probability theory and other analytical procedures, more work is needed to fully integrate economic aspects of fire management to systematically achieve optimal management strategies. To manage effectively, risk should be objectively characterized and institutionalized such that managers conform to an agency-wide decision making framework. This will necessitate framework development including an objective assessment of values at risk and the degree of risk involved with a range of fire management scenarios.

Finally, the policy states that decision making capabilities and data support will be improved. Currently, decision support systems and computer models are used to estimate fire behavior and effects for both wild and prescribed fire. Behavior models include BEHAVE (Andrews 1986), RXWINDOW (Andrews and Bradshaw 1990), and FARSITE (Finney 1996). Similarly, computer systems have been developed to schedule fire use (Bradshaw and Fischer 1981) and to evaluate fire management prescriptions (Bevins and Fischer 1983, Reinhardt 1991). Models designed for stand-level analysis of fire behavior and effects include NEXUS (Scott and Reinhardt 1998), FOFEM (Reinhardt and others 1997), and the fuel and fire extension to the forest vegetation simulator, FFE-FVS (Hardy and Reinhardt 1998). Although such models are important at the stand level, they are not currently formulated to evaluate long-term economic effects of fire management programs. Economic research to evaluate efficiency will be

essential to implement effective fire management plans. Finally, it will be important to achieve consistency across agencies to develop databases that will uniformly support management decisions.

Discussion

The Federal Wildland Fire Policy of 1995 focuses primarily on reintroducing fire into the ecosystem to minimize hazard and the threat of catastrophic wildland fires. Policies are designed to promote reintroduction of fire and enhance agency cooperation and support. Although the policy addresses important economic issues with respect to efficiency and cost effectiveness, implementation of such policies could be problematic depending upon the degree to which community and public support is achieved. Although at an increased cost, social acceptance and education will play a crucial role in the future of fire management and will become increasingly important as populations residing in the wildland urban interface continue to grow. The public, often without regard for efficiency, typically ignores the risks resulting from increasing and unnatural fuel loads, not realizing the potential for damage and loss. Policy that focuses on education and information will likely be one of the key elements in achieving effective fire management in the future.

If fire management policies are to be effective over the long term, it may be necessary to increase total current expenditures and focus more on presuppression activities rather than suppression. Because fuel loads have reached unprecedented levels, fire management efforts will likely take several years to begin controlling the problem. To this effect, forested lands will require intensive management at a scale not seen before. Not only will this be expensive, it will likely be socially unacceptable because of increased emissions, reduced esthetics, and perceptions of risk. Economic research will be important to identify the value of such trade-offs and to compare costs and benefits over the long term.

Related to the effects of presuppression versus suppression, fire programming budgets will have to be revised to support fire management objectives. The unlimited emergency suppression funding has the potential to increase total fire management costs beyond what is optimal and creates a disincentive to invest in presuppression activities such as prescribed burning. Without a policy change in budgeting procedures, unlimited funding will continue to increase total fire management costs while annual budgets remain under-funded.

Fire management over the past century has been greatly influenced by prevailing management philosophies and social values of the times, both of which change in response to scientific advancement. As past fire policies and social beliefs are manifested in a continually changing ecosystem, new information will become available and can be effectively incorporated into the evolving fire management policy. Issues likely to become more important and further complicate fire management are the increasing danger and threat of catastrophic wildland fire, particularly as it affects the wildland-urban interface; the increasing need to burn more extensive areas of forested lands to effectively reduce such threats; increasing costs in relation to the greater number of acres burned; and increasing social and regulatory pressures. If policy makers can achieve a balance among these issues and gain social acceptance, they can begin to effectively address fire management problems through the next millennium.

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Reducing the Wildland Fire Threat to Homes: Where and How Much?¹

Jack D. Cohen²

Abstract

Understanding how ignitions occur is critical for effectively mitigating home fire losses during wildland fires. The threat of life and property losses during wildland fires is a significant issue for Federal, State, and local agencies that have responsibilities involving homes within and adjacent to wildlands. Agencies have shifted attention to communities adjacent to wildlands through pre-suppression and suppression activities. Research for the Structure Ignition Assessment Model (SIAM) that includes modeling, experiments, and case studies indicates that effective residential fire loss mitigation must focus on the home and its immediate surroundings. This has significant implications for agency policy and specific activities such as hazard mapping and fuel management.

The threat of life and property losses during wildland fires is a significant issue for Federal, State, and local fire and planning agencies who must consider residential development within and adjacent to wildlands. The 1995 USDA Forest Service *Strategic Assessment of Fire Management* (USDA Forest Service 1995) lists five principal fire management issues. One of those issues is the "loss of lives, property, and resources associated with fire in the wildland /urban interface" (p. 3). The report further identifies "the management of fire and fuels in the wildland /urban interface" as a topic for further assessment. Because this is more than a Forest Service issue, the National Wildland/Urban Interface Fire Protection Program, a multi-agency endeavor, has been established for over a decade and is sponsored by the Department of Interior land management agencies, the USDA Forest Service, the National Association of State Foresters, and the National Fire Protection Association. This program also has an advisory committee associated with the multi-agency National Wildfire Coordinating Group. These examples indicate that the wildland fire threat to homes significantly influences fire management policies and suggests that this issue has significant economic impacts through management activities, direct property losses, and associated tort claims.

The wildland fire threat to homes is commonly termed the wildland-urban interface (W-UI) fire problem. This and similar terms (e.g., wildland-urban intermix) refer to an area or location where a wildland fire can potentially ignite homes. A senior physicist at the Stanford Research Institute, C.P. Butler (1974), coined the term "urban-wildland interface" and described this fire problem:

In its simplest terms, the fire interface is any point where the fuel feeding a wildfire changes from natural (wildland) fuel to man-made (urban) fuel. ...For this to happen, wildland fire must be close enough for its flying brands or flames to contact the flammable parts of the structure (p. 3).

In his definition, Butler provides important references to the characteristics of this problem. He identifies homes ("urban") as potential fuel and indicates that the distance between the wildland fire and the home ("close enough") is an important factor for structure ignition. How close the fire is to a home relates to how much heat the structure will receive.

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These two factors, the homes and fire proximity, represent the fuel and heat "sides" of the fire triangle, respectively. The fire triangle--fuel, heat, and oxygen--represents the critical factors for combustion. Fires burn and ignitions occur only if a sufficient supply of each factor is present. By characterizing the home as fuel and the heat from flames and firebrands, we can describe a home's ignitability. An understanding of home ignitability provides a basis for reducing potential W-UI fire losses in a more effective and efficient manner than current approaches.

Ignition and Fire Spread are a Local Process

Fire spreads as a continually propagating process, not as a moving mass. Unlike a flash flood or an avalanche where a mass engulfs objects in its path, fire spreads because the locations along the path meet the requirements for combustion. For example, C.P. Butler (1974) provides an account from 1848 by Henry Lewis about pioneers being caught on the Great Plains during a fire:

When the emigrants are surprised by a prairie fire, they mow down the grass on a patch of land large enough for the wagon, horse, etc., to stand on. They then pile up the grass and light it. The same wind which is sweeping the original fire toward them now drives the second fire away from them. Thus, although they are surrounded by a sea of flames, they are relatively safe. Where the grass is cut, the fire has no fuel and goes no further. In this way, experienced people may escape a terrible fate (p. 1-2).

It is important to note that the complete success of this technique also relies on their wagons and other goods not igniting and burning from firebrands. This account describes a situation that has similarities with the W-UI fire problem.

A wildland fire does not spread to homes unless the homes meet the fuel and heat requirements sufficient for ignition and continued combustion. In the prairie fire situation, sufficient fuel was removed (by their escape fire) adjacent to the wagons to prevent burning (and injury) and the wagons were ignition resistant enough to not ignite and burn from firebrands. Similarly, the flammables adjacent to a home can be managed with the home's materials and design chosen to minimize potential firebrand ignitions. This can occur regardless of how intensely or fast spreading other fires are burning. Reducing W-UI fire losses must involve a reduction in the flammability of the home (fuel) in relation to its potential severe-case exposure from flames and firebrands (heat). The essential question remains as to how much reduction in flammables (e.g., how much vegetative fuel clearance) must be done relative to the home fuel characteristics to significantly reduce the potential home losses associated with wildland fires.

Insights for Reducing Ignitions from Flames

Recent research provides insights for determining the vegetation clearance required for reducing home ignitions. Structure ignition modeling, fire experiments, and W-UI fire case studies provide a consistent indication of the fuel and heat required for home ignitions.

The Structure Ignition Assessment Model (SIAM) (Cohen 1995) assesses the potential ignitability of a structure related to the W-UI fire context. SIAM calculates the amount of heat transferred to a structure from a flame source on the basis of the flame characteristics and the flame distance from a structure. Then, given this thermal exposure, SIAM calculates the amount of time required for the occurrence of wood ignition and flaming (Tran and others 1992). On the basis of severe-case assumptions of flame radiation and exposure time, SIAM calculations indicate that large wildland flame fronts (e.g., forest crown fires) will not ignite wood surfaces (e.g., the typical variety of exterior wood walls) at distances greater than 40 meters (Cohen and Butler [In press]). For example, the incident radiant heat flux, the amount of radiant heat a wall would receive from flames, depends on its distance from the fire. That is, the rate of radiant energy

per unit wall area decreases as the distance increases (*fig. 1*). In addition, the time required for a wood wall to ignite depends on its distance from a flame front of the given height and width (*fig. 1*). But the flame's burning time compared to the required ignition time is important. If at some distance the fire front produces a heat flux sufficient to ignite a wood wall, but the flaming duration is less than that required for ignition, then ignition will not occur. At a distance of 40 meters, the radiant heat flux is less than 20 kilowatts per square meter, which corresponds to a minimum ignition time of greater than 10 minutes (*fig. 1*). Crown fire experiments in forests and shrublands indicate that the burning duration of these large flames is on the order of 1 minute at a specific location.³ This is because these wildland fires depend on the rapid consumption of the fine dead and live vegetation (e.g., forest crown fires).

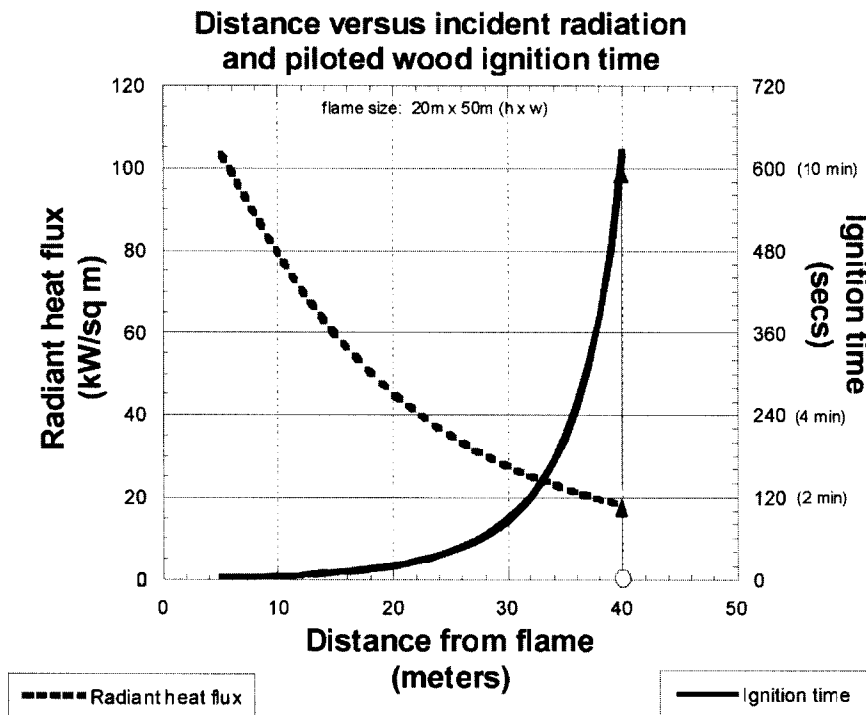


Figure 1

SIAM calculates the incident radiant heat flux (energy/unit-area/time reaching a surface) and the minimum time for piloted ignition (ignition with a small ignition flame or spark) as a function of distance for the given flame size. The flame is assumed to be a uniform, parallel plane, black body emitter.

Experimental fire studies associated with the International Crown Fire Modeling Experiment (Alexander and others 1998) generally concur with the SIAM calculations. Data were obtained from instrumented wall sections that were placed 10 meters from the forest edge of the crown fire burn plots. Comparisons between SIAM calculations and the observed heat flux data indicate that SIAM overestimates the amount of heat received.⁴ For example, the SIAM calculated potential radiant heat flux for an experimental crown fire was 69 kW / sq meter as compared to the measured maximum of 46 kW / sq meter. This is expected since SIAM assumes a uniform and constant heat source and flames are not uniform and constant. Thus, the SIAM calculations for an actual flame front represent a severe-case estimate of the heat received and the potential for ignition. The SIAM distances represent an upper estimate of the separation required to prevent flame ignitions (*fig. 1*).

Past fire case studies also generally concur with SIAM estimates and the crown fire observations. Analyses of southern California home losses done by the Stanford Research Institute for the 1961 Belair-Brentwood Fire (Howard and others 1973) and by the University of California, Berkeley, for the 1990 Painted Cave Fire (Foote and Gilless 1996) are consistent with SIAM estimates and the experimental crown fire data. Given nonflammable roofs, Stanford Research

³Unpublished data on file, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana.

⁴Unpublished data on file, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana.

Institute (Howard and others 1973) found a 95 percent survival with a clearance of 10 to 18 meters, and Foote and Gilles (1996) at Berkeley found 86 percent home survival with a clearance of 10 meters or more.

The results of the diverse analytical methods are congruent and consistently indicate that ignitions from flames occur over relatively short distances---tens of meters not hundreds of meters. The severe-case estimate of SIAM indicates distances of 40 meters or less. Experimental wood walls did not ignite at 10 meters when exposed to experimental crown fires. And, case studies found that vegetation clearance of at least 10 meters was associated with a high occurrence of home survival.

As previously mentioned, firebrands are also a principal W/UI ignition factor. Highly ignitable homes can ignite during wildland fires without fire spreading near the structure. This occurs when firebrands are lofted downwind from fires. The firebrands subsequently collect on and ignite flammable home materials and adjacent flammables. Firebrands that result in ignitions can originate from wildland fires that are at a distance of 1 kilometer or more. For example, during the 1980 Panorama Fire (San Bernardino, California), the initial firebrand ignitions to homes occurred when the wildland fire was burning in low shrubs about 1 kilometer from the neighborhood. During severe W/UI fires, firebrand ignitions are particularly evident for homes with flammable roofs. Often these houses ignite and burn without the surrounding vegetation also burning. This suggests that homes can be more flammable than the surrounding vegetation. For example, during the 1991 fires in Spokane, Washington,⁵ houses with flammable roofs ignited without the adjacent vegetation already burning. Although firebrands may be lofted over considerable distances to ignite homes, a home's materials and design and its adjacent flammables largely determine the firebrand ignition potential.

Research Conclusions

SIAM modeling, crown fire experiments, and W/UI fire case studies show that effective fuel modification for reducing potential W/UI fire losses need only occur within a few tens of meters from a home, not hundreds of meters or more from a home. This research indicates that home losses can be effectively reduced by focusing mitigation efforts on the structure and its immediate surroundings. Those characteristics of a structure's materials and design and the surrounding flammables that determine the potential for a home to ignite during wildland fires (or any fires outside the home) can be referred to as home ignitability.

The evidence suggests that wildland fuel reduction for reducing home losses may be inefficient and ineffective: inefficient because wildland fuel reduction for several 100 meters or more around homes is greater than necessary for reducing ignitions from flames; ineffective because it does not sufficiently reduce firebrand ignitions. To be effective, given no modification of home ignition characteristics, wildland vegetation management would have to significantly reduce firebrand production and potentially extend for several kilometers away from homes.

Management Implications

These research conclusions redefine the W/UI home fire loss problem as a home ignitability issue largely independent of wildland fuel management issues. Consequently, this description has significant implications for the necessary actions and economic considerations for fire agencies.

One aspect of the Forest Service approach to reducing the W/UI fire problem is to determine where the problem is and focus fuel management activities in those areas. *The Strategic Assessment of Fire Management* (USDA Forest Service 1995) states:

⁵Unpublished video data on file, Rocky Mountain Research Station, Fire Sciences Laboratory, Missoula, Montana.

The Forest Service should manage National Forest lands to mitigate hazards and enhance the ability to control fires in the wildland /urban interface. The risk of wildland fire to communities can be lessened by reducing hazards on Forest Service lands adjacent to built-up areas.... Broad-scale assessment processes for the next generation of forest plans should identify high risk areas related to the wildland / urban interface.... The highest risk areas within the United States should be identified and mitigation efforts directed to these locations (p. 20).

It describes a costly, intensive, and extensive W-UI hazard mapping and mitigation effort specifically for reducing home fire losses. As described, this approach is not necessary.

The congruence of research findings from different analytical methods suggests that home ignitability is the principal cause of home losses during wildland fires. Any W-UI home fire loss assessment method that does not account for home ignitability will be critically non-specific to the problem. Thus, to be reliable, land classification and mapping related to potential home loss must assess home ignitability. Home ignitability also dictates that effective mitigating actions focus on the home and its immediate surroundings rather than on extensive wildland fuel management. Because homeowners typically assert their authority for the home and its immediate surroundings, the responsibility for effectively reducing home ignitability can only reside with the property owner rather than wildland agencies.

Mapping Home Loss Potential

The evidence indicates that home ignitions depend on the home materials and design and only those flammables within a few tens of meters of the home (home ignitability). The wildland fuel characteristics beyond the home site have little if any significance to W-UI home fire losses. Thus, the wildland fire threat to homes is better defined by home ignitability, an ignition and combustion consideration, than by the location and behavior of potential wildland fires.

Home ignitability has implications for identifying W-UI fire problem areas and suggests that the geographical implication of the term "wildland-urban interface" as a general area or zone misrepresents the physical nature of the wildland fire threat to homes. The wildland fire threat to homes is not where it happens related to wildlands (a location) but how it happens related to home ignitability (the combustion process). Therefore, to reliably map W-UI home fire loss potential, home ignitability must be the principal mapping characteristic.

Wildland Fuel Hazard Reduction

Extensive wildland vegetation management does not effectively change home ignitability. This should not imply that wildland vegetation management is without a purpose and should not occur for other reasons. However, it does imply the imperative to separate the problem of the wildland fire threat to homes from the problem of ecosystem sustainability due to changes in wildland fuels. For example, a W-UI area could be a high priority for extensive vegetation management because of aesthetics, watershed, erosion, or other values, but not for reducing home ignitability. Vegetation management strategies would likely be different without including the W-UI home fire loss issue. It also suggests that given a low level of home ignitability (reduced wildland fire threat to homes), fire use opportunities for sustaining ecosystems may increase in and around W-UI locations.

W-UI Home Loss Responsibility

Home ignitability implies that homeowners have the ultimate responsibility for W-UI home fire loss potential. Because the ignition and flammability

characteristics of a structure and its immediate surroundings determine the home fire loss potential, the home should not be considered a victim of wildland fire, but rather a potential participant in the continuation of the wildland fire. Home ignitability, i.e., the potential for W-UI home fire loss, is the homeowner's choice and responsibility.

However, public and management perceptions may impede homeowners from taking principal responsibility. For example, the Federal Wildland Fire Management, Policy, and Program Review (1995) observes, "There is a widespread misconception by elected officials, agency managers, and the public that wildland /urban interface protection is solely a fire service concern" (p. 23). In the *Journal of Forestry*, Beebe and Omi (1993) concur, stating that, "Public reaction to wildfire suggests that many Americans want competent professionals to manage fire flawlessly, reducing the risks to life, property, and public lands to nil" (p. 24). These statements agree with Bradshaw's (1988) description of the societal roles in the W-UI problem. He observes that homeowners expect that fire protection will be provided by others. Contrary to these expectations for fire protection, the fire services have neither the resources for effectively protecting highly ignitable homes during severe W-UI fires, nor the authority to reduce home ignitability.

An Alternative

Specific to the W-UI fire loss problem, home ignitability ultimately implies the necessity for a change in the relationship between homeowners and the fire services. Instead of all pre-suppression and fire protection responsibilities residing with fire agencies, homeowners should take the principal responsibility for assuring adequately low home ignitability. The fire services become a community partner providing homeowners with technical assistance as well as fire response in a strategy of assisted and managed community self-sufficiency (Cohen and Saveland 1997). For success, this perspective must be shared and implemented equally by homeowners and the fire services.

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S e s s i o n

V

**Resource Valuation Requirements in Strategic
Fire Planning**

Chair: Hayley Hesseln

Effects of Fire on the Economic Value of Forest Recreation in the Intermountain West: Preliminary Results¹

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Abstract

Visitors to National Forests in Colorado, Idaho, and Wyoming were asked how their visitation rates would change with the presence of a high-intensity crown fire, prescribed fire, and a 20-year-old high-intensity fire at the area they were visiting. By using pairwise t-tests, visitors to forests in Colorado showed a statistically significant decrease in recreation trips per year with the presence of a recent crown fire, a smaller but still significant decrease with a recent prescribed burn, and with a 20-year-old high-intensity fire. A multivariate test of the effect of fire on the demand curve for recreation was conducted by using the travel cost method. The multivariate test indicates that years since last fire does have a statistically significant effect on visitation in Colorado, Idaho, and Wyoming, although the effect is very small.

The growing societal awareness of maintaining a healthy environment and the rising costs of Federal and State fire fighting is forcing public agencies to incorporate the economic value of non-marketed resources into their fire management planning and decisions (González-Cabán 1993). However, estimating the impacts of fire on resources and the resulting economic consequences is a difficult problem for fire managers because of a lack of information on the effects of fire on recreation use. However, recreation is one of the dominant multiple uses in the intermountain west. Field users of the USDA Forest Service National Fire Management and Analysis System use the Resources Planning Act (RPA) values for recreation but do not have a solid empirical basis for determining how recreation use changes immediately after fire and over the recovery interval (Loomis 1997). Flowers and others (1985) found that "The studies demonstrate that no clear consensus has been reached on the duration for which fire effects on recreation should be measured or valued. The duration effects ranges from 6 months to 7 years among the studies.... The choice of duration is subjective and somewhat arbitrary because research on the question is scant" (p. 2). Flowers and others (1985) used an iterative bidding contingent valuation method question to estimate the change in value of recreation with low and high-intensity fires in the Northern Rocky Mountains. Although they found only minor effects, part of this may be due to baseline valuations elicited. Even in the no fire case their values per Recreation Visitor Day were less than \$1, a value far below values in the literature at the time. These values were about half this amount immediately after fire, a sizeable percentage reduction. Use levels were estimated to fall by nearly half immediately after fire.

Englin (1997) noted in his recent review of the literature on the effects of fire on recreation, "At present there are few studies quantifying the impacts of fire on the non-timber values produced by forests" (p. 16). Two revealed preference studies focus on the effects of fire on canoeing in the Canadian boreal forests (Boxall and others 1996, Englin and others 1996). A very recent master's thesis (Hilger 1998) applied a Poisson count data model to compare before and after recreation use levels with fire in the Alpine Lakes Wilderness Area in Washington State. Hilger found a substantial drop-off in recreation use during the year of the

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fire and up to 2 years after the fire. However, by the third year use had surpassed the pre-fire use levels. The value per day of recreation did not change with the fire, however.

The National Fire Management Analysis System (NFMAS) requires incorporation of fish, wildlife, recreation, and wilderness as well as environmental values into calculation of the dollar amount of net value change. Little guidance is available as to how field personnel are to estimate the change in recreation visitor days over time with different fire intensity levels. No information exists on recreation visitors reaction to prescribed fires that might be set to reduce the likelihood of high-intensity, crown fires.

This paper begins to fill the gap by reporting empirical estimates of how recreation use and benefits change with different ages from fire and fire intensity levels. In addition, the similarity and differences between visitors' response to fire in Colorado, Idaho, and Wyoming is investigated to determine if the visitors reaction to fire from these three areas are similar enough that they might be generalized to other intermountain forests.

Research Design

Demand Estimating Method

This research combines data on actual number of trips taken by visitors to locations on National Forests unaffected and affected by fire with contingent visitation for alternative fire situations. The alternative fire scenarios are depicted by using color photos from National Forests. The quantity of trips is regressed on travel cost to the site, characteristics of the visitors, and attributes of the recreation site, including years since last fire and fire intensity level. This basic form yields a travel cost method demand function of the general form:

$$(1) \text{ Trips} = \text{function} (\text{Travel Cost, Demographics, Fire Characteristics})$$

Since Trips per person per year to the site is an integer, a count data regression model is appropriate (Creel and Loomis 1990, Englin and Shonkwiler 1995). This model yields a functional form equivalent to a semi-log, with the log of the dependent variable. With this functional form, the average net benefit to the visitor per day (i.e., consumer surplus or net willingness to pay) is the reciprocal of the slope coefficient on the travel cost variable (Creel and Loomis 1990). If the mean of trips is not equal to the variance of trips, the overdispersion parameter (α) will be significant and a negative binomial form of the count data is appropriate.

By examining the significance level on fire related variables, we can test whether the quantity of visits changes with years since the fire and estimate any corresponding change in economic value. We can also test whether the reaction to fire is similar among visitors to National Forests in Colorado, Idaho, and Wyoming by including slope and intercept shift variables for these states. The travel cost method is one of the methods recommended for use by Federal agencies (U.S. Water Resources Council 1983).

Overall Sample Design

The physical forests selected for the study will form the basis for the analysis. The locations form a "subject-specific" (SS) sample frame which is distinct from a population-averaged (PA) sample frame (Zeger and others 1988). There are two compelling reasons for adopting an SS sample frame approach. First, a PA approach would require the definition of all possible members of fire damaged forests, a daunting task. Second, without knowledge of the universe of fire affected forests the only sampling scheme that could be operationalized would be a simple random draw. This may or may not include the policy relevant areas for any given level of sampling effort. An example of this difficulty is the Eastern

Lake Survey (Englin and others 1997). The survey randomly sampled 763 lakes from the population of all lakes greater than 4 hectares in the eastern United States. A subsequent random sample of 1,144 anglers in 1989 found that only 61 of the 763 lakes were actually visited by a sampled angler. From the perspective of valuing recreational angling the cost associated with 702 of those lakes was wasted. Unfortunately, it would be impossible to specify a stratified sampling scheme without the information gathered from the 702 lakes. Population based sampling is simply very costly.

Clearly, the problem would be even worse in a forestry setting. At least lakes can be defined in a very straightforward way when digitizing maps. Forest conditions resulting from fires could be much more challenging. The alternative is to apply the SS approach and accept the more restrictive nature of the sample. The key restrictions are the dependence upon the distributional assumptions made in the econometric analysis and proper specification of the model. We used an SS-based analysis because of the cost associated with PA-based samples in this context.

Sampling Strategy in Colorado

Only two sample strata were consistently available with data judged by the U.S. Forest Service as reliable: acres burned and year of fire. Data on vegetation was incomplete for some forests and measured by three different indicators, such as vegetation type, cover class, and fuel model. In addition, the vegetation data was not reliable (Jon Skeels, personal communication). Repeated calls were made to each National Forest office to obtain fire statistics (acres, year burned, vegetation type, and recreation use). This resulted in some data for some Forests. This information was supplemented with Kansas City Fire Analysis System (KFAS) data. Inconsistencies were noted, especially on the Gunnison National Forest and were reconciled during site visits. We also attempted to ascertain the magnitude of recreation use of each burned area (e.g., areas with high, moderate or low use). This was judged by the fire specialists or by proximity to roads/trails. Although not being able to stratify by other characteristics such as Fire Intensity Level (FIL), this is included as candidate site characteristic in the recreation demand model.

Thus, the main strata were fires of size D (100-299 acres), E (300-999 acres), F (1,000-4,999 acres) and G (5,000+ acres). The years were grouped into fire ages with zero equal to the year of the survey (1998) and counting back from there (e.g., 1-2, 3-6, 7-10, 11-20, and 21-29). This puts the earliest dates at 1970. Equivalent unburned sites were sampled on each of the National Forests to provide a control and represent the seventh age category.

There were 28 possible cells (four sizes times seven time periods). Our goal was to have at least one fire site in each cell of the matrix. Unfortunately, there were several empty cells with no fire data. Thus, three National Forests in Colorado were selected that provided coverage of most of the cells and were logistically functional (e.g., one Forest was on the way to another Forest or was proximate to Fort Collins). The Arapaho-Roosevelt, Gunnison-Uncompaghre and Pike-San Isabel National Forests were chosen in Colorado. This provides two-front range National Forests and one interior National Forest.

In Colorado we can generalize to class D and larger fires and areas with a full range of low, moderate, and high recreation use. We believe we can generalize from the forest sites sampled within a cell to the other forests within that same cell. Specifically, the common cells between the Arapaho-Roosevelt, Pike, and Gunnison National Forest areas sampled and other Rocky Mountain Region forests that were not sampled. For example, many of the Arapaho-Roosevelt fires were similar in size and date to fires on the Wind River and the Bighorn National Forests, although we are able to test this indirectly for the Wind River National Forest.

Each District Office on each of the three National Forests were visited to obtain more refined data on specific location of fires relative to recreation use. This was followed by on-site visits to ascertain visibility of the fire from the recreation trail. In some cases, we could not locate any evidence of fire or the trailhead was not signed or very difficult to find, making it unlikely there would be many recreation users (this dropped a couple of sites from the Arapaho-Roosevelt, and two on the Pike National Forest-each site had only one user/vehicle and one of these required a four-wheel drive vehicle to get there). On the Pike National Forest, two of the recreation areas/trailheads that were burned in the Buffalo Creek fire were closed to public use, so were obviously eliminated. On the Gunnison National Forest, two sites were dropped because of very low levels of recreation use (Soap Creek: three cars over the entire Memorial Day weekend, verified with trail register and campground host) or primarily dispersed use, with no central trailhead or recreation sites (Barrett Creek had just two to three informal pull out areas with no trailheads). One site on the Gunnison could not be reached unless one had a high clearance four-wheel drive vehicle. However, we found two sites on the Arapaho-Roosevelt National Forest that were off of a dirt road and have very low use levels (Lone Pine and Kilpecker). Thus, the full spectrum of recreation use levels is represented.

Counting sampling days and travel days in between, there were about 35 sampling days during the main summer recreation season. Each site was sampled one weekday and one weekend day each month of July and August. A total of 10 sites over the three National Forests were sampled. This schedule generally allowed one sampling rotation of two days (1 weekday and 1 weekend day) at nearly all of the Colorado sites. Specific sites sampled and days sampled include:

Arapaho-Roosevelt National Forest	Number of days
Mt. Margaret	4
Greyrock Trail	4
Kilpecker Area and Lone Pine	4
Youngs Gulch	2
Blue Lake	2
Pike National Forest	
Colorado Trail	5
Devil's Lookout	4
Gunnison National Forest	
Summerville Trailhead	4
North Bank Campground/Doc Park Trailhead	3
Caves/ Double Top	3

Sampling in the Idaho and Wyoming Sites

The Bridger-Teton and Wind River National Forests were the focus of the sampling in Wyoming. Trailheads located in the Teton and Gros Ventre Wilderness areas were sampled. Specifically, 13 trailheads were sampled that gave hikers access to 25 distinct trails/ destinations. The majority of these trails were in Wilderness areas. In Idaho, there were 11 trailheads providing access to 25 distinct trails/ destinations. The majority of these were in the Sawtooth National Recreation Area. All surveying occurred in the months of July and August 1998. Specific sites sampled and the number of days sampled include:

Wind River National Forest	Number of days
Big Sandy	4
Green River	3
Elkhart Park	5
Boulder Lake	3

Bridger Teton National Forest

Granite Creek	4
Cache Creek	2
Death Canyon	1
Goodwin Lake	2
Gros Venture	2

Idaho National Forests

Redfish Lake Trailhead	5
Alturas Lake Trailhead	3
Baker Creek	3
Prairie Creek	2
Iron Creek Trailhead	7
Pioneer Cabin (Sun Valley)	1
Lake Stanley Trailhead	4
Pettit Lake	2

Survey Protocol

The interviewers stopped individuals as they returned to their cars at the parking area. The interviewers introduced themselves, gave their university affiliation, and gave a statement of purpose. Then the interviewer gave a survey packet to all individuals in the group 16 years of age and older with the following statement:

We would like you to take a survey packet with you today as you are leaving. You do not need to fill it out now, although you can if you like. Rather take the survey packet with you and answer the questions on your way home or when you return home. All the instructions are included. The packet includes a postage paid return envelope. The survey asks a few questions about your visits to this area and how they may be affected by different fire management options. We think you will find the survey interesting. Your answers will be used by the U.S. Forest Service in deciding the level of fire prevention and response to fires.

In Colorado, we further stated:

I do need you to fill out your name/ address on this card, so we can send you a reminder if we don't get the survey back in the next couple of weeks. However, your name/ address will not be associated with your responses. Your responses are completely confidential and you will not be put on any mailing lists as a result of this survey.

Surveys were also handed out by University of Nevada-Reno students at sites in Wyoming and Idaho. In addition, at sites in Wyoming, surveys were given to the Campground Host to hand out to visitors as well.

Survey Structure

Recreation users were first asked to check off their primary or main recreation activity. Then they were asked their travel time and travel distance to the site. This was followed by questions about their travel costs and a dichotomous choice contingent valuation question for participating in their current activity (e.g., hiking, camping) at the site where they were contacted at for the existing forest condition. Individuals were asked whether visiting the site was their primary purpose, one of many equally important reasons, or a minor stop. Then individuals were asked about past years trips, current number of trips so far this year and planned trips to the site during the rest of the year. In addition, we asked how these trips would change if their trip costs increased. By sampling at different hiking trails or sites, some of which had not been burned, some recently

burned, and some burned in the past, we could determine whether there is a statistical relationship between site visitation and fire effects by using current observed behavior.

The next portion of the survey presented three contingent behavior scenarios:

- One-half of the trail experienced a recent high-intensity crown fire. This was depicted with a color photo of standing blackened trees that had no needles. The photo was taken from the Buffalo Creek fire that occurred 2 years earlier.
- One-half of the trail experienced a light (prescribed) burn. The photo used had the lower trunk and lower branches of the trees burned, there were reddish colored needles on these lower branches, but the tops of the trees were green and there were numerous other green trees present.
- One-half of the trail reflected an old (20 years) high-intensity fire. The photo used had standing dead trees with white tree trunks, downed trees, and younger newer, green trees.

For each scenario, visitors were asked how their trips to the site where they were intercepted would change if half the trail were as depicted in the photo. The questionnaire concluded with standard demographic questions.

The advantage of the fire effects in the stated preference portion of the survey is that a wide range of the impacts of fire on forest conditions could be conveyed to each visitor. These photos allowed us to determine the effect that high-intensity crown fires, prescribed fires, and older fires have on recreation use.

The increase in trip costs used as bid amounts were \$3,7,9,12,15,19,25,30,35, 40 and 70. These were based on limited pretesting and previous recreation studies.

The surveys were pretested at two of the National Forests. Individuals were asked to fill out the survey and provide any comments or feedback. A few questions were clarified as a result of comments during the pretests. No focus groups were performed as the subjects of this survey were on-site users who were knowledgeable about the areas they were visiting and had first hand experience in trading their travel time and travel cost for access to the recreation sites studied.

Inclusion of Non-survey Site Characteristics

To isolate the effects that fire may have on recreation visitation, it is important to control for non-fire related site attributes. The candidate measures of site attributes chosen included those that have been significant in past forest recreation studies (Englin and others 1996). Thus, several site characteristics such as elevation gain of the trail, miles of dirt road, elevation of trail above sea level, etc., were chosen on this basis. Fire attributes included the fire age, acres burned, and fire intensity level. These data were obtained from the USDA Forest Service KFAS system and verified with the District Offices. By the sample design, there was a range of small to large fires and low-intensity prescribed fires to high-intensity fires. There was also a range of ages of fires, although most were fairly recent. There were six unburned sites in Colorado.

Preliminary Results

Survey Returns

In Colorado, the interviewer took note of refusals. There were only 14 refusals out of 541 contacts made. A total of 527 surveys were handed out. Of these, 354 were returned after the reminder postcard and second mailing to non-respondents. Thus, the overall response rate was 67 percent. In Idaho and Wyoming, a total of 1,200 were handed out. Of these, 325 were returned. The response rate was 27 percent. This is lower because of the inability to send reminder postcards and second mailings to non-respondents.

Descriptive Statistics

Given the sampling at trailheads on the Colorado National Forests, it is not surprising that most of the visitors in Colorado were hiking (59 percent) or mountain biking (30 percent). The average visitor was on-site for 5 hours and had three persons in their group. About two-thirds of the trips were single-destination trips. The typical Colorado visitor drove 77 miles (one-way) and had gas costs of \$12 (for a gas cost per round trip mile of 7.8 cents).

Of most interest to this study is the comparison of current trips taken with trips that would be taken with the three fire scenarios. A typical visitor had taken about two trips and planned two more during the remainder of the season. These four trips would decrease to 2.3 trips with a recent, high-intensity fire over 50 percent of the trail (*table 1*). The four trips would decrease to 3.35 trips if 50 percent of the trail had been burned by a light fire or prescribed fire. If 50 percent of the trail visited would have shown the effects of an old (20 years) high-intensity fire, they would take 2.96 trips instead of 4 trips. Pairwise t-tests of each fire scenario against the baseline trips all indicate a statistically significant reduction in trips at the 0.01 level. This pattern is consistent with the number of visitors that would change their trip visitation rate if there were a high-intensity fire (55 percent would change), low-intensity (23 percent), and old high-intensity (33 percent). Both the trip reduction and visitor reduction is similar to Flower and others (1985).

The demographics of the Colorado sample included 56 percent male respondents with an average age of 36.5 years and education of 16.3 years (*table 1*). More than 90 percent of the sample worked outside the home and visited the recreation site on weekends, holidays, or paid vacation. The average household size was 2.54 people. The typical household earned \$67,232.

The visitors to the Idaho and Wyoming National Forests were slightly older (43.4 years) than the Colorado visitors but had nearly identical education levels (college graduate). A lower proportion of the visitors returning surveys handed out in the Idaho and Wyoming National Forests were males (44 percent) as compared to Colorado National Forest visitors. However, in terms of timing of visits, nearly identical proportions visited on weekends, holidays, or vacations (75 percent) as did Colorado visitors. However, distance traveled of Idaho and Wyoming forest visitors was much greater at 613 miles.

Table 1-Descriptive statistics of the Colorado sample and Idaho/Wyoming sample.

Variable	Colorado	Idaho/Wyoming
Travel distance	77 miles	613
Previous season	2.06	1.42
Trips so far this year	2.19	1.77
Trips planned	1.77	1.06
Total trips this season	3.96	2.84
Trips if high-intensity fire	2.33	1.74
Trips if low-intensity fire	3.35	2.45
Trips if old high-intensity fire	2.96	2.02
Demographics of visitors		
Percent males	56 pct	44 pct
Age	36.55	42.4
Education	16.3	16.1
Work	90 pct	80 pct
Visit on weekend, holiday vacation	78 pct	75 pct
Household income	\$67,232	\$70,179

The reaction of Idaho and Wyoming National Forest visitors to fire was similar to Colorado visitors in terms of the response pattern of trips. Specifically, total trips dropped the most from current condition to the high-intensity fire scenario, dropping from 2.84 trips per year currently to 1.742 trips per year if 50

percent of the trail had been burned by a 2-year-old high-intensity fire. A recent low-intensity or prescribed fire only results in a slight decrease in visitation from current levels, a reduction from 2.84 trips to 2.45 trips per year. Like Colorado, the drop in visitation with an older (20 years) high-intensity fire is in between these other two scenarios, a reduction from 2.84 trips to 2.02 trips with the older, high-intensity fire.

Multivariate Statistical Analysis

The data set makes possible estimation of several types of travel cost method (TCM) models. Annual visitation models require combining information on trips actually taken at the time the visitor received the survey and trips planned during the remainder of the season. This is necessary so that all visitors are considered equally, since some were sampled early in the season and others later in the season. Without this adjustment, those sampled earlier in the season would appear to take fewer trips. Given the non-negative integer nature of reported trips, a count data model is often most appropriate (Englin and Cameron 1996). At this point in time we have not corrected for endogenous stratification that may result from on-site sampling (Englin and Shonkwiler 1995). These models estimated the relationship between visitation and fire age and fire intensity as well as visitor demographics.

As is required to meet the assumptions of the TCM for travel cost to be interpreted as a price paid for visiting the site, individuals visiting multiple sites on a given trip from home (i.e., a multi-destination trip) were excluded from the analysis. Further, individuals reporting one-way travel times greater than 5 hours were also deleted as many of these individuals may also be on multi-destination trips. This is necessary because it would be misleading to attribute the entire trip cost to any one particular site. In addition, for this preliminary analysis the dataset was limited to individuals that answered all the key questions necessary to estimate the price variable (e.g., they answered travel time and travel cost questions in the survey). Individuals who traveled less than 1 mile to the site were also deleted on the presumption they either live adjacent to the site (which violates another assumption of the travel cost method; Parsons 1991) or were on a multi-destination trip and were staying at a resort or location nearby the site for other purposes such as camping. Further analysis of this data set will involve relaxing some of these conditions to include more individuals in the analysis. For this preliminary, combined, three-state analysis, the travel cost variable was defined as an individual's gasoline cost plus their travel time valued at one-fourth the wage rate. This approach is consistent with the U.S. Water Resources Council (1983) guidelines for TCM.

Three State Model

Preliminary results for the combined Colorado, Idaho, and Wyoming datasets are shown in *table 2*. The travel cost variable is statistically significant and yields a value of \$47 ($1/0.021$) per day of recreation on the Wyoming National Forests. The travel cost (price) slope interaction terms for Colorado and Idaho are also statistically significant. This indicates that the Colorado and Idaho visitors demand curve has a different price slope and benefits per trip. Specifically, Colorado net benefits per day is \$95 ($1/(0.021-0.010446)$), while the Idaho net benefits per day is \$123 ($1/(0.021-0.012866)$). However, the demand curve intercept shifter for Colorado is not significant, implying no difference with Wyoming. In this full model, the Idaho demand curve intercept shifter is significant, although it becomes insignificant in the restricted model.

Table 2-Negative binomial pooled regression models for Colorado, Idaho, and Wyoming.

Variable	Unrestricted model			Restricted model			
	Coefficient	Std error	P-Value	Coefficient	Std error	P-Value	Mean
Constant	2.7258	0.37480	0.000	2.307	0.4982	0.000	
TravelCost	-0.021062	0.002333	0.000	-0.0261	0.0022	0.000	11.41
TravelCost*FireAge	-0.50938E-04	0.12787E-03	0.690				-221.3
ColoradoTravelCost	0.010446	0.0019513	0.000	0.01205	0.00239	0.000	-7.909
IdahoTravelCost	0.012866	0.0022554	0.000	0.01606	0.00303	0.000	-18.73
Age	0.0084770	0.004151	0.041				36.42
Education	-0.09393	0.02278	0.000	-0.05239	0.033	0.121	16.32
Income	0.49237E-05	0.9774E-06	0.000	0.531e-05	0.159e-05	0.000	57470.00
FireAge	-0.77023E-03	0.2526E-03	0.002	-0.8027e-03	0.334e-03	0.015	-63.09
Colorado	-0.18393	0.18407	0.317				0.6177
Idaho	-0.60969	0.17228	0.000	-0.3027	0.202	0.135	0.1872
Alpha	1.4007	0.8635E-01	0.000	2.53	0.161	0.000	
Number of observations	1015			1015			
Log likelihood function	-2250.768			-3926.028			
Restricted log likelihood	-3885.351			-4292.666			
Chi-squared	3269.167			733.275			
Degrees of freedom	10			7			
Significance level	0.000			0.000			

By using this information, the transferability of values across National Forests in Colorado, Idaho, and Wyoming can be evaluated using the significance of the state intercept dummies for Colorado and Idaho (Wyoming is base case) and state price slope interaction variables. In both the unrestricted and restricted models, the significance of the Colorado and Idaho price slope interaction terms suggests there may be different underlying demand curves for these two areas from each other and from Wyoming. As such, transferring demand functions from one state to the other would lead to a biased estimate of net benefits per day of recreation. The error would be smaller for Colorado and Idaho transfers as the reduced model shows consumer surplus of \$71 and \$98, respectively. On the positive side, the insignificance of the state intercept dummies suggests the state demand equations might do a reasonable job predicting trips.

The FireAge variable is statistically significant as an intercept shifter in the demand function but not in terms of affecting the slope of the demand function (i.e., FireAge* TravelCost is insignificant). Thus, trips per person does change (slightly) with FireAge, but value per day does not. FireAge has a negative sign, since FireAge is measured as years since fire, with -1 being 1 year, -10 being 10 years, and so forth. Therefore, the longer it has been since a fire, recreation use increases. Because the negative binomial model is equivalent to a semi-log of the dependent variable, the marginal effect of FireAge is calculated as the anti-log of the demand function. By using the Restricted model, such calculations indicates that trips per person has a very small response to fire age. Specifically there is a change of about a one-tenth of a trip per person as FireAge increases from a recent fire to a 10- year-old fire to no fire (FireAge equals 50). We still need to test whether there are different FireAge coefficients by state, by using a state FireAge interaction term.

Conclusions

The responses to photos depicting recency and intensity of fires suggest that the number of trips per visitor falls in the first few years after a forest fire. The reduction is fairly small for prescribed fires and much larger (about two trips per person) for a recent high-intensity fire. Pooling these contingent behavior responses with actual trip responses to wildfires in Colorado, Idaho, and Wyoming and performing a multi-variate analysis suggests a very small effect of age of the fire on visits per person. The average response across all three states model, which pools contingent behavior and actual behavior, suggests each visitor would change their trips by less than one-tenth a trip per year.

Additional analysis is planned to evaluate if incorporating fire via a simple dummy variable for presence or absence of fire is a better way to model fire effects than age from fire. In addition, inclusion of other recreation site characteristics will be tried.

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OWLECON: A Spreadsheet Program for Calculating the Economic Value to State Residents from Protecting Spotted Owl Habitat from Fire¹

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Abstract

The spreadsheet program, OWLECON, was developed to allow managers to quickly calculate the economic value of reducing fire risk to California and northern spotted owl habitat in California and Oregon. The program draws from surveys performed of California and Oregon residents. The user simply types in the current average annual acres burned and the expected acres that would burn with different fire management projects or scenarios. The program will calculate the economic value to people living around the particular National Forest. The annual value per acre protected in the fire management unit is calculated. This can be inputted into the National Fire Management Analysis System (NFMAS) so that the northern spotted owl can be considered with other multiple use resources in the net value change computation.

Federal agencies have begun to recognize that in addition to protection of traditional multiple uses, other environmental values need to be incorporated into fire decision-making (González-Cabán 1993, González-Cabán and Chase 1992). These values often reflect public desire to know that rare and distinctive ecosystems exist (e.g., existence value; Krutilla 1967) and will be protected for future generations (bequest value), as well as being available for visits at future times (option value). In addition to recreation, these three values are sometimes referred to as total economic value (Randall and Stoll 1983). Vaux and others (1984) conducted the first study on the influence of fire on the economic value of forest recreation and found that "Willingness-to-pay is an appropriate measure for valuing the effects of fire on forest recreation" (p. 1). This is consistent with Federal benefit-cost directives that require use of willingness-to-pay (WTP) as a measure of benefits (U.S. Water Resources Council 1983).

This paper discusses the development of a spreadsheet program, OWLECON, that used data from two contingent valuation studies (CVM) of the willingness-to-pay (WTP) of residents in Oregon and California to protect old-growth habitat of the northern spotted owl from catastrophic fire.

Non-Market Valuation Methodology

The contingent valuation method (CVM) uses a questionnaire or survey to create a hypothetical market or referendum and then allows the respondent to use it to state or reveal his or her WTP for recreation, option, existence, and bequest values (Mitchell and Carson 1989). The first part of a CVM survey presents the current and proposed change in quantity or quality of the resource. Second, the respondent is told how they would pay for the proposed change. Then the provision rule is made clear: if you agree to pay you get the proposed quantity/quality, if you do not agree to pay you remain at the current quantity/quality level. The recommended WTP question format asks respondents to state whether they would pay a specific dollar amount that varies from respondent to respondent (Arrow and others 1993). The use of responses from a survey to measure WTP is not without objections, such as the validity of responses.

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Specifically, the question arises if the respondents would actually pay the dollar amounts they state or agree to pay in the survey. There have been dozens of studies testing the validity of stated WTP by comparison of values derived from other methods. A summary of these studies by Carson and others (1995) determined that CVM derived estimates of WTP for recreation were somewhat less than actual behavior-based methods for valuing recreation. Although concerns remain about the degree of accuracy of CVM estimates of WTP for existence and bequest values for natural resources that are unfamiliar to the public, the method has been shown in empirical test-retest studies to be reliable at eliciting such values (Loomis 1989, 1990). CVM is a recommended method for use by Federal agencies for performing benefit-cost analysis (U.S. Water Resources Council 1983) and for valuing natural resource damages (U.S. Department of Interior 1994), and it has been upheld by the Federal courts (U.S. District Court of Appeals 1989). A "blue ribbon panel" co-chaired by two Nobel laureate economists concluded that CVM can produce estimates reliable enough to be the starting point for administrative and judicial determinations (Arrow and others 1993).

Study Design

To statistically estimate willingness to pay as a function of acres of old-growth habitat protected from catastrophic fire, survey data was compiled from two separate CVM studies. The first study was a survey of Oregon households to determine their WTP for a fire prevention and control program to protect northern spotted owl habitat in Oregon. The second study was a survey of California and New England households to determine their WTP to reduce fire intensity and acres burned of spotted owl habitat in old-growth forests in California and Oregon.

In both the California and Oregon study a survey booklet was developed to provide the basic information to respondents before eliciting their WTP. In the Oregon resident study, respondents were asked to value a fire prevention and control program for 3 million acres of old-growth forests in Oregon that have been designated as Critical Habitat Units (CHU's) for northern spotted owls. This was emphasized by a half page map of western Oregon showing the CHU's. Below the map, the current number and size of fires in Oregon old-growth forests were described. Then the elements of the Fire Prevention and Control Program that would reduce the acres burned were listed (Loomis and González-Cabán 1997).

In the Oregon survey the respondents were told: *"Adoption of this improved fire prevention and control program would on average reduce the number of acres of Critical Habitat Units that burn by half, a reduction of 3,500 acres a year (from 11 square miles to 5.5 square miles) on publicly owned old-growth forests in Oregon."* The narrative of the California Program was similar to this and reduces the acres of high intensity fires and total acres of old-growth forests burned by all intensities of fire by 20 percent or 2,850 acres each year in California. California residents were asked their WTP to reduce the amount of old-growth forests in northern spotted owl CHU's in Oregon that burn each year by 20 percent or 1,400 acres. The third program was a combined California and Oregon Program, reducing acres burned by 4,250 acres.

Willingness-to-Pay Questions

Households were told that there were insufficient funds to pay for the improved fire prevention and control programs. In the California survey (Loomis and González-Cabán 1996, 1997) respondents were then asked, *"Thinking about Program B, which reduces the proportion of high intensity fires and also includes a 20 percent reduction in the acreage of old-growth forest that burns each year, if Program B*

were the only program available and your household was asked to pay \$X each year to help pay for Program B, would you pay this amount?"

YES NO (don't know)

The same basic wording and series of WTP questions were also used to ask the WTP question for the Oregon Program and for a single program that combined the California Program and Oregon fire control program. In the Oregon resident survey, they were asked just about the Oregon program (Loomis and others 1994, 1996; Loomis and González-Cabán 1994, 1996, 1997).

The means by which all households would pay was a closed-ended or dichotomous choice question. The dichotomous choice format mimics an actual vote by asking if the person would vote (e.g., pay) for the program if it cost the household a particular dollar amount each year. The respondent has only to decide if the value to him or her is worth at least this price or not.

Sample Design

For the Oregon study, questionnaires were sent to a random sample of 1,000 Oregon households. The sample was provided by Survey Sampling Inc.⁴ For the California /New England Study, random digit dialing was used to initially contact 737 households in California and 709 households in the New England. A total of 499 California households and 449 New England households were scheduled for in-depth interviews, reflecting an initial participation rate of 68 percent and 63.3 percent, respectively. The 948 scheduled households were mailed the survey booklet that contained the background information on old-growth forests, maps, and information about current and proposed fire management programs. A total of 358 interviews out of 499 were completed that were scheduled in California for a completion rate of 72 percent. In New England, 314 interviews out of 449 were completed, yielding a 70 percent completion rate.

Survey Response Rates

For the Oregon study, 425 surveys were completed and returned, which after deleting undeliverable surveys and deceased individuals yielded a response rate of 49.4 percent. The response rate is typical for a general population survey using a first mailing-postcard-second mailing without any financial incentives. For the California/New England study, the overall response rate for California was 49 percent and 44 percent for New England. The respondents were slightly older (by 3-4 years) than the state population levels and slightly more educated (by about one year). In estimating WTP we adjusted for these differences by setting the age and education at the respective state levels based on census data. The samples had a slightly higher proportion of males (52-53 percent male) as compared to the population proportion for California (50 percent) and New England (48.3 percent). There was less than a 10 percent difference between the household income of the sample and that of the respective populations.

Statistical Results

To allow managers to calculate WTP for reductions in expected acres burned, a logit WTP function was estimated, including a variable for acres. Because economic theory suggests diminishing marginal value to greater and greater reductions in acreage burned, the natural log of acres were estimated. The results of the logistic regression were determined, with the log of the probability of paying the bid amount as the dependent variable (*table 1*). Both the bid amount and the natural log of acres were statistically significant at the 0.01 level. This suggests respondents carefully considered the details of the survey questions. In particular, the negative and statistically significant coefficient on the bid variable

⁴Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

Table 1—Logit equation for respondents' willingness-to-pay (WTP) reduce fires in old-growth forests in California and Oregon.

Variable	Coefficient	T-Stat	P-Value
Constant	-4.7087	-4.93	0.000
Lacres ¹	0.4182	3.93	0.000
Ogexist ²	0.178	2.84	0.005
Envgimp ³	0.3654	4.08	0.000
Educ ⁴	0.0367	2.13	0.033
Ages ⁵	-0.0107	-3.58	0.000
Donate ⁶	0.2933	2.88	0.004
Bid ⁷	-0.011	-14.45	0.000

¹Log of acres.²The importance of knowing that old-growth forests exist.³The importance of the quality of the environment.⁴Education level in years.⁵Persons age in years.⁶Dummy variable for whether respondents had contributed to an environmental organization in the past 12 months.⁷Dollar amount respondents were asked to pay.

suggests that the higher the dollar amount respondents were asked to pay, the less likely they would pay. This demonstrates they considered seriously the dollar amount they were asked to pay. The fact that acres is significant implies that the amount of habitat protected influenced their probability of paying a given dollar amount.

Details of Computer Program

A Microsoft-DOS computer and a Lotus 123 spreadsheet program (Lotus version 2.0 or higher) is the preferred hardware and software. If running a Windows version of Lotus 123 you will need Microsoft Windows. Lotus 123 for DOS or 123 for Windows can also be run in Windows 95. The program should also operate under Quatro Pro or Microsoft Excel by importing the Lotus spreadsheet. However, all instructions are for Lotus.

Running the Program

To run this program, five variables will need to be changed that are displayed on the screen. The five variables are: **current acres that burn; with management action acres that burn; forest-wide acres protected by management action; number of people living around the national forest** (these are the primary beneficiaries from reducing fire risk in spotted owl habitat); and the **number of years the management action provides reduced fire risk** to the acres protected in the National Forest. This information is collected from a specific management area.

Current Acres That Burn

This number represents the average annual acres that burn in a management area with the current level of fire prevention and control programs in place. Enter this number in cell **D19**.

With Management Action Acres That Burn

The average annual number of acres that would burn after implementation of the proposed fire prevention and control program should be estimated. The number of acres that burn annually after a fire prevention and control program have been implemented should be less than the acres that burn with no management practices. If the estimate shows a number for **management acres that burn** that is greater than current acres that burn, the economic results section will display an error (ERR). Enter the annual acres that burn after the implementation of the fire program in cell **D20**. (The program will calculate a value for acres that no longer burn [D19-D20]. This number represents the current acres that burn subtracted from **management action acres that burn**).

Forest-wide Acres Protected by Management Action

Fire managers often express the effectiveness of a fire prevention and control program as the broad area that will receive a reduction in the probability of wildfire. For example, performing a brush removal program on 1,000 acres throughout a 10,000 acre area provides reduced likelihood of catastrophic fire to the entire 10,000 acres, even though only 500 acres less will burn in any given year as a result of the brush removal. Nonetheless, the reduction in fire risk occurs on the entire 10,000 acres. Thus, 10,000 acres are protected in this example. This number of acres often corresponds to what one would analyze in the National Fire Management Analysis System (NFMAS) for acres protected. Thus, the resulting value per acre protected calculated by OWLECON could be input into NFMAS for the net value change analysis.

Number of People Living Around the National Forest

The number of persons living around the National Forest is input as a conservative measure of the number of beneficiaries of the fire management action. This will be multiplied by the estimated value per person to arrive at the total benefits arising from the fire management action. Usually this number would be the number of people living in the multi-county impact area used for IMPLAN input-output analyses or social impact analyses. The counties and their populations can often be determined by looking in the Forest Plan.

Years Action Is Effective

To calculate a present worth or present value for the management action, the number of years for which the action is effectively reducing fire risk needs to be entered. If the management action such as a prescribed burn or brush removal would reduce the number of acres burned by the same amount for 10 years, enter 10. In other words, enter the number of years for which the management action protects the number of acres entered. If the management action provides a declining amount of protection, in each year after the management action the simple discounting feature used in this program will overstate the effect and should not be used. In this case, set the **years** variable to the duration of time in which the management action provides a constant annual benefit. The program can be run for each of these "time steps" and then sum the stream of benefits discounted outside of the program using the spreadsheet.

It is important to note that the program estimates of benefits is most valid for acreages that no longer burn between 150 acres and 50,000. Using it with acres less than this or more than this involves a high degree of extrapolation beyond the range of the data used in the statistical analysis, and the results may be less accurate. Also, as each acreage figure is entered, the program will recalculate the values in the results section. These numbers will not be correct until all three acreages are entered. After the last number is entered, then the values in the Economic Results Section will be correct for the acreage scenarios that have been created.

Spreadsheet Example for Habitat of Northern and California Spotted Owl in California

This section will illustrate use of the program and interpretation of the results for the Calowl2.wk1 file in OWLECON. For the example, we set the value of the five input variables as:

- Current Acres that burn = 10,000; type into cell D19.
- With Management Action Acres that burn = 9,000; cell D20.
- Forest-wide Acres Protected by Management Action = 200,000; cell D23.
- Number of People Living Around National Forest = 1,000,000; cell D25.
- Number of Years Action is Effective For = 10; cell D26.

Interpreting the Results

The annual per person benefit of \$25 is the amount that an average person living around the National Forest would pay each year to reduce 1,000 acres of crown or catastrophic fire in northern or California spotted owl habitat (*table 2*). These dollars represent the sum of recreation use value and existence value for knowing the spotted owl exists in their natural habitat as well as bequest value. Bequest value is the benefit received from knowing that protection today provides spotted owls and their habitat to future generations. The U.S. District Court of Appeals for the District of Columbia (1989) has required the Federal government to include these values when calculating natural resource damage assessments. These types of values are included in U.S. Fish and Wildlife Service Environmental Impact Statements (EIS) on the benefits of protecting endangered species (U.S. Fish and Wildlife Service 1994).

Because protection of the 1,000 acres of spotted owl habitat from burning simultaneously provides benefits to people living around the National Forest, the \$25 is multiplied by the number of persons living around the National Forest. Although research indicates that benefits of preserving the northern and California spotted owl is nationwide (Loomis and González-Cabán 1996), to be conservative we have chosen only to expand the values to those 1 million people living around the National Forest. Usually this number would be the number of households living in the multi-county impact area used for IMPLAN input-output analyses. This area can be determined by looking in the Forest Plan.

The product of value per household and the 1 million people surrounding the National Forest results in a total value of \$25 million. When divided by the number of acres that no longer burn, this value is \$25,006 per acre that no longer burns. This would be the value to compare to the per acre costs of the fire management action used to achieve the 1,000 acre reduction in area burned. Dividing the total economic value by the number of acres protected yields a value of \$125 per acre. This would be the value input into NFMAS to calculate the net value change from protecting 1 acre of California or northern spotted owl habitat from burning. Protecting officially designated northern spotted owl critical habitat and California spotted owl areas in California are not distinguished. All of the dollar figures are in 1995 dollars. If the base year dollars of the NFMAS analysis is different or if the costs are in current year dollars, the benefit figure will need to be scaled up. This is usually done by applying a price index such as the Implicit Price Deflator or Consumer Price Index.

Table 2-Sample OWLECON results for California.

Habitat for Northern and California Spotted Owl in California		
Date of Analysis - October 11, 1998		
I. INPUT VARIABLES		Acres
Current Acres that burn		10,000
With Mgmt Action Acres that burn		9,000
Acres that no longer burn		1,000
Forest-wide Acres Protected by Mgmt Action		200,000
Number of People Living Around National Fores		1,000,000
Number of Years Action is Effective For		10
II. ECONOMIC RESULTS		
Annual Economic Values		
Per Person Total Value	\$ Per Acre	\$Per Acre
Benefits Around N.F.	No Longer Burning	Protected
\$25 \$25,006,294	\$25,006	\$125
Present Value @ 4 pct. Per	Present Value Q 4 pct.	
Acre No Longer Burning	Per Acre Protected	
\$202,823	\$1,014	

Because the WTP equation is non-linear, doubling the amount of acres protected from burning will not double the total economic value. This makes economic sense, as protecting each additional acre contributes slightly less benefit than protecting the first few acres. The present value of the benefits arising from the acres that no longer burn is calculated at the USDA Forest Service interest rate of 4 percent for the number of years specified as an input (*table 2*). The present value per acre protected is also valued.

Conclusion

Public land managers in California and Oregon now have a powerful tool for estimating the economic benefits of reducing acres burned of old-growth forests that are habitat of the northern and California spotted owl. Judicious use of this tool should aid managers in developing budget requests for fuels reduction and prescribed fire programs to protect spotted owl habitat.

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Incorporating Non-Market Values in Fire Management Planning¹

Douglas B. Rideout,² John B. Loomis,³ Philip N. Omi²

Abstract

The increased importance of non-market values in land management planning means that fire management and planning needs to more directly and effectively incorporate them into the planning and decision-making process. This means developing better understanding of the role of non-market valuation in the context of fire effects in prevention and suppression. It also means better knowledge and systems for including fire effects on non-market values and how they affect optimal fire management decisions. Non-market and especially non-use values can be incorporated into the cost plus net value change (C+NVC) framework for use with current land management planning systems. An innovative coupling of the C+NVC framework with cost effectiveness analysis (CEA) is introduced.

Introduction

Two economically-based decision frameworks are of particular relevance to fire management programs and budgeting. These are benefit cost analysis (BCA) and cost effectiveness analysis (CEA). CEA is a sub-set of BCA and is used where benefits are particularly difficult to quantify for comparison with cost. CEA has particular relevance to the treatment of non-market or non-use values in fire management. Each of these frameworks is explained below, including their relevance to the fire management situation.

To determine if a particular fire management action represents an improvement in social well being, one must be able to measure the net gain in benefits. Benefits of market goods are more straightforward. But many resources occurring on public lands are non-marketed. As shown here, the benefits of these non-market resources can also be measured in dollar terms. All of these benefits plus the cost savings to society from fire prevention policies such as prescribed burns can be added together. These benefits can only be added together if all resources, market and non-market, are measured with a consistent valuation framework and accounting stance.

This paper reviews current approaches to valuing and incorporating non-market values into fire management research and suggests an innovative approach to the treatment of non-market values that may be difficult or infeasible to quantify.

Benefit-Cost Analysis (BCA)

Benefit cost analysis is the practice of comparing the gains and losses of a particular activity or project with the purpose of aiding social decision-making. BCA can be performed *ex ante* or *ex post* (Boardman and others 1996). *Ex ante* BCA is used as a planning and evaluation tool where the analysis is performed before the project is undertaken to aid in the evaluation of alternatives including project scale. *Ex post* BCA is performed after the project is completed so that actual costs and benefits (as opposed to projected) can be compared. Each has relative advantages. *Ex ante* analysis is most often applied in fire management.

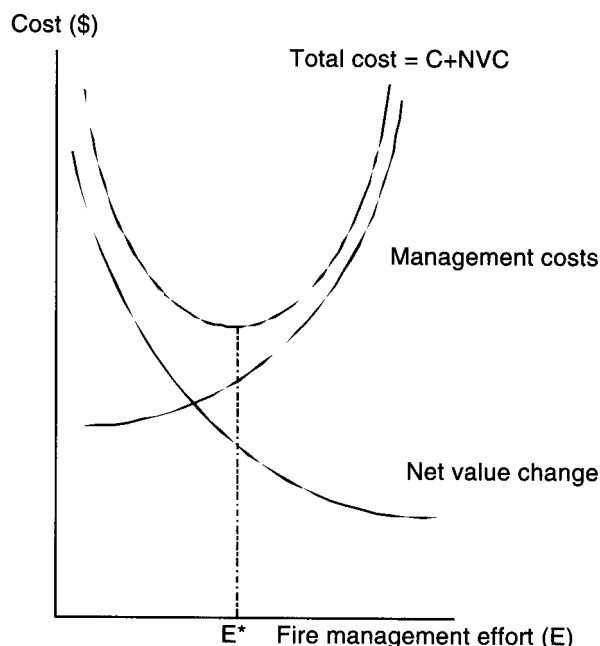
¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Policy, and Planning: Bottom Lines, April 5-9, San Diego, California.

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Figure 1

Generalized fire management model.

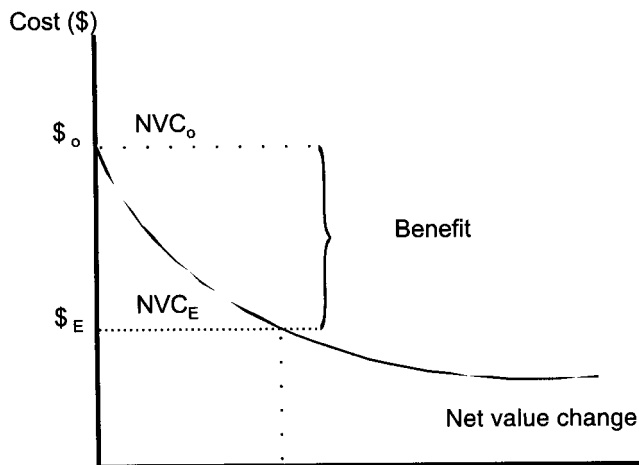


Benefit Cost Analysis and Cost Plus Net Value Change

Ex ante BCA is appropriate where the benefits and costs of the proposed activity can be identified, quantified, and scheduled. The fire-economics model, C+NVC, is an example of BCA where the cost of suppression and presuppression are compared with net value change (NVC). This overall framework is illustrated in the familiar C+NVC diagram (*fig. 1*), which shows fire management costs (suppression and presuppression) increasing as more effort is applied (Rideout and Hesseln 1997). Net value change (net damage) declines as fire effort is increased. Together these two effects illustrate a tradeoff in cost where management costs are balanced by fire damage (NVC). The bowl-shaped curve is defined by the vertical sum of management costs and NVC. The minimum of the bowl identifies the cost minimizing amount of fire management effort to apply (E^*). Although the cost of fire management activities is conceptually straightforward (practicalities aside) the benefit of fire management (including non-market value effects) can be problematic.

The benefit of fire management is, conceptually, included by reducing the total damage as a result of fire management activities. The total benefit of a particular level of fire management is the difference between NVC with no effort and NVC at the specified level of effort (*fig. 2*). For example, the total benefit of fire management effort level E is denoted by the distance ($\$_E - \$_0$) (*fig. 2*). In the C+NVC model, this benefit is compared with its corresponding costs in suppression and presuppression to form the classic bowl shaped. By locating the minimum point on the bowl, the user of the model is comparing the quantifiable benefits with the quantifiable costs to perform a BCA.

In this way, BCA is consistent with and used in much of the current efforts of fire management and planning. More specifically, this implementation of BCA is intended to be the intellectual foundation of the overall National Fire Management Analysis System (NFMAS) process. A pragmatic difficulty occurs where benefits cannot be adequately scheduled or quantified for inclusion into the BCA process. Some implementations of BCA will treat "non-quantifiable" benefits as items to consider as the quantifiable aspects of BCA are performed.

**Figure 2**

Benefits of fire management.

Special Considerations Regarding Benefits

The treatment of benefits is of particular concern and reflects the overall purpose of this project. First, we approach general considerations regarding the treatment of benefits and then address a framework for incorporating non-use values into the C+NVC model using CEA.

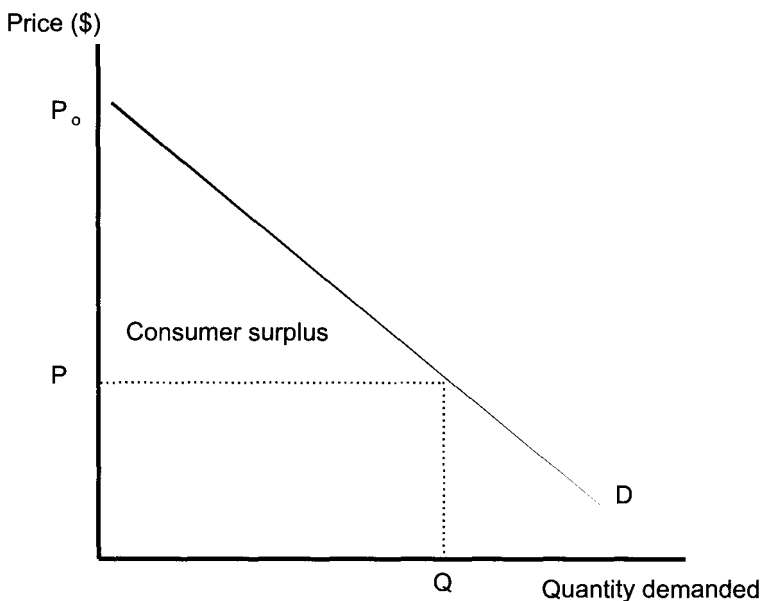
Valuation Philosophy and Willingness-to-Pay (Demand)

This report takes the anthropocentric view which states that people (as opposed to natural objects) are the ultimate source of value. Goods and services provide benefits only if an individual or group is benefited. The magnitude of the benefits received is determined by each individual's own judgment of how much better off they are. Thus, economists measure an individual's benefits from fire prevention or fire management as the maximum amount of income they would be willing and able to pay for the program rather than go without. It is important to note that willingness-to-pay in the form of income is simply a proxy for willingness to give up other goods and services to have the resource or project under study. By using monetary measures, we are able to compare the value of various alternatives and incorporate diverse kinds of benefits directly into the analysis. This is known as "monetizing the benefits." Some beneficial effects may be impractical, too expensive or too difficult to accurately monetize. This can be especially applicable to non-use values. Such non-monetized beneficial effects can, under certain conditions, be included into the C+NVC analysis.

The methodology chosen to measure the benefits of resources must allow us to compare marketed resources and nonmarketed resources affected by fire. To obtain consistency in valuation for both marketed and nonmarketed resources, economists rely on values measured from consumer's demand curves and businesses' supply or cost curves to measure net willingness-to-pay. Consumers' willingness-to-pay is measured by consumer surplus, which is defined as the area beneath a consumer's demand curve but above the actual price paid. This area is illustrated as the triangle labeled *Consumer surplus* in the demand curve shown in figure 3.

For most goods, consumers receive a surplus or gain in excess of what they pay-this is consumer surplus. For goods and services that are consumable in small units such as hamburgers, cans of soda, etc., it is only the last unit purchased that is worth just what the consumer paid. Because the last unit has a value to the consumer exactly equal to what he or she paid, there is usually no consumer surplus on the last unit bought.

Figure 3
Demand and consumer surplus.



This same logic would hold if the area of public land provided an identical mix of recreational activities (in the same environmental setting) and of the same quality that could be found at other public lands located exactly the same distance from all visitors as this area. Thus, if there were numerous less congested perfect substitute sites available at the same price (distance) and having the same quality (setting, aesthetics, etc.), then a fire at one such recreation area would result in little change in consumer surplus (i.e., people will not be willing to pay anything additional to protect this site from fire). However, it is rare that there are less congested perfectly identical substitute recreation areas located at the same distance to users.

In general, if a catastrophic fire results in a loss of a recreation area, there will be a price increase for consumers who lived closer to that site than any other site providing the same mix of recreation activities and the same setting. That is, these consumers will now have to travel further to obtain that same type of recreation. As such, the price increase translates into a loss in consumers' surplus, just like any other price increase would.

In cases where the substitute sites are so congested that they are rationed by advance reservation or permits, no new visitors can be accommodated and the entire existing consumer surplus would be lost. This situation is typical in East Coast states and a few western states such as California. If the other site does not restrict entry of visitors, the additional visitors may often impose congestion costs on existing visitors to these sites and hence indirectly reduce the quality at the existing sites. Because loss of a recreation site or changes in recreation quality due to fire result in non-marginal changes that do affect prices or quality, there is a change in consumer surplus. This arises in part because recreation is not a homogeneous product traded in national markets. Because of the high travel costs associated with recreation, 80 to 90 percent of visitors travel from within a few hours distance to most recreation sites, i.e., they have localized markets.

There is no inconsistency here in terms of using market price to derive stumpage values for timber and then using consumer surplus for recreation. Both are measures of willingness-to-pay. Price is a measure of gross willingness-to-pay at the margin for one more unit of the good. Thus, all resources affected by fire are compared using the same conceptual measures of value: willingness-to-pay.

Economists are also wary of substitution effects. For example, some fire management programs may enhance one type of resource at the expense of another, such that some public land users lose while others gain. What can be said about an alternative fire policy that makes one person better off but another

worse off? If it is possible to add individual valuations together, it is possible to determine if the sum or total of the valuations is the highest with any alternative. By using the criteria of total benefits, an alternative is preferred if it yields the greatest value of total output.

Accounting Stance

Although benefits are defined from the viewpoint of individuals, often one person's gain is offset by another person's loss. Some resource reallocations do not represent net gains in economic efficiency, but rather simply a transfer of economic activity from one person to another or one location to another. Although this seems very straightforward, if we add one element of realism to this example, we can illustrate a frequent confusion over what constitutes benefits.

For example, assume a policy is proposed to restore fire to the Coeur d'Alene basin in northern Idaho. If the analyst measuring the benefits of this program worked for the State of Idaho and took a state view, then he or she might find that this program resulted in losses to residents living in Idaho. This state viewpoint is one accounting stance. The term "accounting stance" refers to an identifiable group of individuals for which benefits and costs count and for which they do not. Thus, with the State of Idaho or local accounting stance, only benefits received in Idaho and only costs incurred by Idaho residents would count. The state analyst would ignore both benefits and costs occurring outside the region of interest. From a national accounting stance, such a state accounting stance is too narrow to reflect all of the benefits and costs to all people.

A national accounting stance is appropriate for most public land resource actions. This is especially true when dealing with management actions on National Forests, National Parks and National Wildlife Refuges or when dealing with the expenditure of Federal funds. In this case, the national interest is clear: citizens of the United States are all owners of these natural resources and provide the funds to manage them. A state accounting stance in this example would result in failure to incorporate any positive externality of the natural fire into benefit-cost calculations. Because one of the reasons for public ownership of resources is to internalize such externalities into public decision making, it is clear that a national accounting stance is required to ensure that the complete benefits and costs of a resource management action are reflected.

The general guidance to the analyst is to measure benefits and costs "to whomsoever they may accrue." Much like dealing with equity in benefit cost analysis, concerns about which states or nations gain and which lose are best dealt with by displaying the distribution of benefits and costs to each political jurisdiction. This is much better than adopting a narrow accounting stance that results in complete omission of certain state's or nation's benefits and costs.

Cost Effectiveness Analysis (CEA)

CEA has particular relevance to non-market issues in fire management and economics. Whereas benefit-cost tools such as NFMAS rely on the quantification of values, values which are difficult or too costly to accurately evaluate can be addressed through the CEA framework adapted for fire management. For example, NFMAS currently only incorporates use-values. Non-use values may be incorporated into the fire management decision making framework by using CEA.

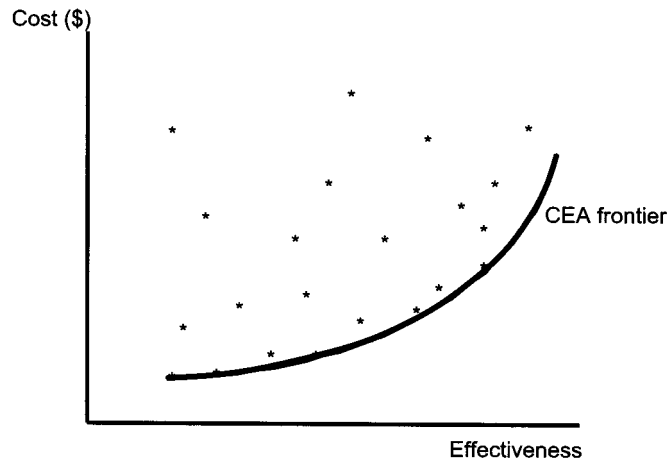
General CEA

CEA was particularly prominent as a technique for addressing the effectiveness of military spending during the cold-war and popularized by then Defense Secretary Robert McNamara. It was defined by William Niskanen (1967) as:

Cost-effectiveness analysis is specifically directed to problems in which the output cannot be evaluated in market prices, but where inputs can, and where the inputs are, substitutable at an exchange relationship developed in the market.

Figure 4

General result of cost effectiveness analysis (CEA).



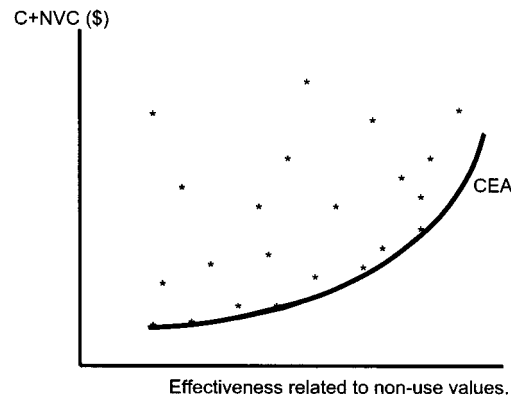
It addresses the problem of maximizing effectiveness subject to a generalized resource constraint measured in dollars. Cost-effectiveness analysis is appropriate when (1) there is no market evaluation of alternative outputs, as in the defense sector... and (2) the resource inputs can be appropriately evaluated at market price (p. 18).

The process of CEA depends upon being able to establish physical measures of accomplishment that can be tracked to cost levels. For example, during the cold-war, the Department of Defense was charged with deterrence as an accomplishment. However, directly measuring and evaluating deterrence was not operable so that an effectiveness measure was used instead. The measure of deterrence effectiveness chosen was the capability of armed forces to inflict fatalities on the Soviet Union. A more peaceful example is that of a family contemplating the purchase of a television set. The benefits of a new television are typically very difficult for a family to assess. Instead, for a given set of features, the family may compare cost with picture quality where picture quality would be the measure of effectiveness.

Although there is much to a full CEA, the overall result can be illustrated where cost is plotted against effectiveness to form the CEA frontier (*fig. 4*). In the illustration particular points (*) are illustrated so as to compare their cost with their effectiveness. Only points on the CEA frontier are cost-effective. Any point on the interior of the frontier could produce more effectiveness at the same level of cost. In this way, points (alternatives) can be compared. In the first stage of comparison, points on the interior of the frontier are identified as inefficient and typically are discarded. In the second stage of analysis, alternatives located along the frontier are considered as to their effectiveness relative to their cost. The choice of alternatives located along the frontier is not directly addressed by CEA, but CEA provides the tool for informed discussions of the cost-effective alternatives. Choices along the frontier are often considered a matter of policy as opposed to scientific investigation.

CEA for Fire Management Systems: Incorporating Non-monetized Values

For values that are impractical or too costly to estimate dollar values (monetize), we can measure physical progress toward accomplishment (effectiveness). For example, preserving or enhancing a measure of bio-diversity could be difficult to reliably monetize. In fuels management problems where the benefits of fuels treatments have been elusive and difficult to measure, effectiveness proxies, such as fuel loading changes provide a measure of effectiveness that can be used in a CEA.

**Figure 5**

Net value change (NVC) and cost effectiveness analysis.

In fire planning and management applications where there are identifiable non-monetized values at risk, the C+NVC model as incorporated into NFMAS or other tools can be used to facilitate the CEA. For example, suppose that in fire management planning protecting a particular site from wildfire is associated with preserving a particular non-monetized value. We can incorporate this into the C+NVC like analysis by tracking how much it will cost to provide increasing levels of protection (effectiveness) to the non-monetized resource in question. On one side, through NFMAS or by using some other tool, we can track the amount of cost in terms of C+NVC associated with various protection alternatives. On the other side we will track and associate the corresponding levels of protection or effectiveness for each level of C+NVC provided (*fig. 5*).

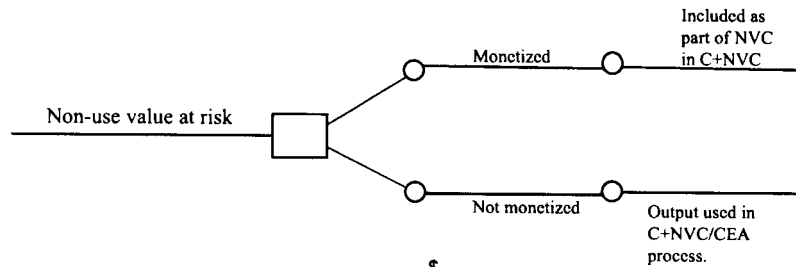
The result of such a CEA process is illustrated in *figure 5*. The interpretation of the illustration is the same as for the generalized CEA, where fire management alternatives (*) on the frontier denote cost-efficient alternatives and alternatives on the interior are inefficient. This allows decision-makers to focus on the cost-effective management strategies and to evaluate the trade-off between fire management costs and the protection of non-monetized value. As currently configured, NFMAS includes the costs of fire management (suppression and presuppression) as well as the cost of resource net damage to use values. The CEA framework for C+NVC, shows how non-monetized values can conceptually be incorporated into the overall analysis for more informed fire management decisions. Improving the measure of non-monetized values poses a trade-off with other fire-management costs and that such improvements will come at increasing cost in C+NVC because of the law of diminishing returns.

Suppose, for example, that we are interested in fire management options at Sequoia, but that we are reluctant to attempt to quantify the benefits of the General Sherman Tree. However, we are very interested in preserving (protecting from wildfire) the tree. To address this issue, we can perform a C+NVC analysis while using fire management alternatives designed to protect this national treasure. The effectiveness of each potential (*ex ante*) treatment can be identified, recorded, and compared with the overall fire management (C+NVC) cost. The CEA will provide decision-makers with the ability to identify cost-efficient options so that informed choices can be made regarding fire management and the level of protection afforded to the tree.

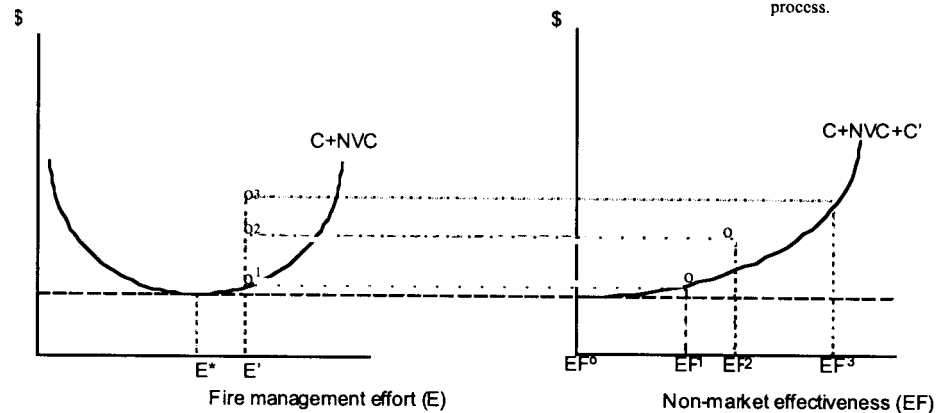
Non-values at risk can be monetized and combined with other resource values as part of the NVC function in the C+NVC models or, in the event that monetization is impractical or unreliable, they can be treated as physical outputs (*fig. 6*). Such outputs or measures of physical accomplishment can be included as part of the C+NVC/CEA process (*fig. 7*).

Figure 6

Monetized and non-monetized values as incorporated into the cost plus net value change/cost effectiveness analysis (C+NVC/CEA) framework.

**Figure 7**

Cost plus net value change (C+NVC) with non-monetized cost effectiveness analysis (CEA).



The analysis illustrated in *figure 7* is valid only under very restrictive conditions; however, it is useful for beginning the discussion on the relationship between C+NVC and CEA analysis. The left panel shows the familiar C+NVC bowl shape with the most efficient level (MEL) of fire management effort at E^* . E^* corresponds with the MEL where non-use values have not been included in the analysis (*fig. 7*). As non-monetized values are included at additional cost, the cost of including them will mean increasing total cost above the minimum of the C+NVC bowl. On the right panel, the point corresponding with E^* is denoted as EF^0 and corresponds with a non-use output level for which no additional cost is incurred (*fig. 7*). Point E' on the left panel denotes an increase in fire management effort and three higher levels of total cost corresponding with three levels of effectiveness in producing the non-monetized benefit. Point one on the left panel corresponds with an increase in total cost and an increase in non-market effectiveness to level EF^1 . Holding the level of fire management effort constant at E' the cost of producing increased effectiveness can be charted for comparison at EF^2 , and similarly at greater cost and effectiveness at EF^3 . Note that level of effectiveness EF^2 is cost-inefficient because it is on the interior of the frontier. Similarly, alternative levels of fire management effort, beyond E' can be modeled (left panel) along with increases in total cost aimed at improving overall non-market effectiveness to trace out the cost-effective frontier produced in the right panel ($C+NVC+C'$). Points along the frontier can then be compared to improve informed decision-making regarding the cost and effectiveness of providing non-monetized benefits. Such comparisons will also be associated with alternative levels of fire management effort as shown in the left panel (*fig. 7*).

Conclusion

Benefit cost analysis can be used to evaluate fire management alternatives within the C+NVC framework. This framework is currently structured to include market and non-market values as demonstrated by the NFMAS process. Special considerations are often necessary in the incorporation of non-market values in the application of willingness-to-pay measures including the treatment of consumer surplus. Many values (use and non-use) are currently not incorporated

into fire management planning because of limitations of planning tools such as NFMAS, difficulties in the measurement of monetized value, and conceptual problems. The C+NVC / CEA process addresses both the monetization issue and the conceptual issue by providing an operationally viable framework for incorporating both monetized and non-monetized benefits into the fire management planning process. CEA is a process developed for addressing the production of objectives that are not practically evaluated in dollar terms. This restricted CEA/C+NVC analysis suggests a potential for advancement in the treatment of non-use values in the evaluation and planning of fire management systems.

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Session

VI

**Fuel Treatment, Prescribed Fire, and Fire Restoration:
Are the Benefits Worth It?**

Chairs: Susan Husari and Melanie Miller

Applying Simulation and Optimization to Plan Fuel Treatments at Landscape Scales¹

J. Greg Jones,² Jimmie D. Chew,² Hans R. Zuuring³

Abstract

Fuel treatment activities are analyzed at the landscape scale by using both simulation and optimization. Simulating vegetative patterns and processes at landscape scales (SIMPPLLE), a stochastic simulation modeling system, is initially applied to assess wildfire risks on the current landscape without management treatments but with fire suppression. These simulation results are input into a multi-resource analysis and geographic information system (MAGIS), an optimization modeling system, for scheduling activities that reduce these risks and address other management objectives. The derived treatment schedules are used in additional SIMPPLLE simulations to examine the change in wildfire risk and other natural processes. Fuel treatment effects are quantified as changes in the predicted extent and intensity of future wildfires and the resulting economic benefits.

Past management practices have excluded fire from what are now known as fire-dependent plant communities. Over time this has resulted in the unnatural build-up of fuels, increasing the probability of catastrophic wildfire (Arno 1996b, USDA Forest Service 1996a). Historically, some of these fire-dependent communities were modified by frequent, low-intensity ground fires; stand-replacing crown fires occurred rarely if at all (Arno 1996a, Williams 1995).

Fuel treatment activities are being applied to address this problem of fuel build-up. But it is not known what strategies are most effective for answering the questions of when, where and how to treat these fuels. Is it more effective to target the acres where the problem is most severe, but where the per-acre treatment costs are very high? Or is it better to target acres that are not now critical, but will become so in the future if not treated? Because the per-acre treatment costs for these areas are less, more acres can be treated with the same budget. How can managers identify the fuel conditions that are most effective to treat without addressing the spatial pattern of fuels and how treatments will be applied over time? Fuel treatments, however, are but one of many issues of concern to land managers. Ultimately management activities must be planned and implemented in view of a variety of objectives and constraints that arise from the Forest Plan and scoping done by forest resource specialists and the public. Managers must be able to develop and evaluate alternatives that address the objectives and constraints that sometimes conflict. This assessment of alternatives and the implementation of the selected alternatives are carried out in a spatial context at the landscape level.

Quantitative techniques are needed by which the spatial arrangement and timing of fuel treatment options can be analyzed in the ecosystem landscape assessment and planning process. These techniques need to address the likely changes in the extent and intensity of wildfire that result from fuel treatments, the economic payoffs in terms of reduced fire suppression costs and net value loss, and finally, impacts on other resources.

The Bitterroot Ecosystem Management/Research Project (BEMRP) is a cooperative project involving the USDA Forest Service's Rocky Mountain Research Station, Bitterroot National Forest, and Northern Region, and The

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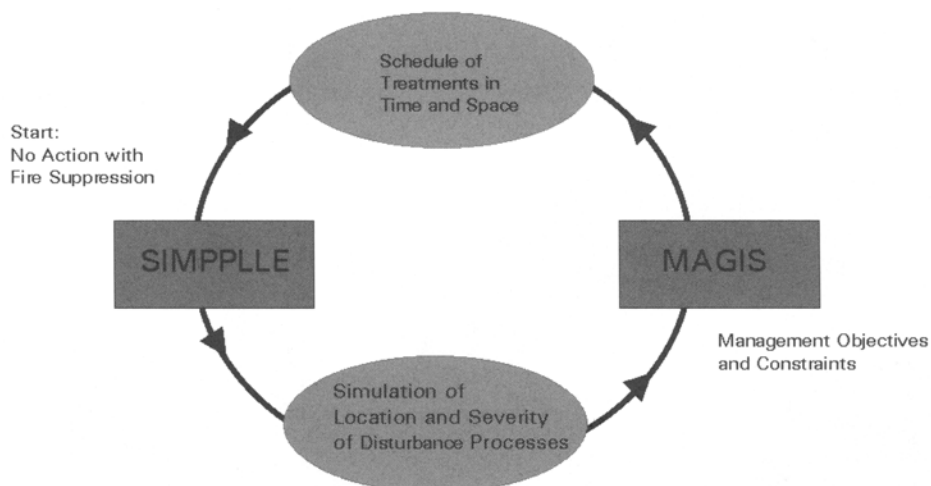
University of Montana. Scientists and land managers in the Landscape Analysis Group of BEMRP have developed and implemented a modeling framework that uses two modeling systems: simulating vegetative patterns and processes at landscape scales (SIMPPLLE) and the multi-resource analysis and geographic information system (MAGIS), that interact with data in a spatial and temporal context. SIMPPLLE is a model that projects changes in vegetation over time and space by using a state/pathway approach (Chew 1995). A vegetative state is defined by dominant tree species, size class, and density as well as association with a habitat type group (Pfister and others 1977). MAGIS is a microcomputer-based spatial decision support system (SDSS) for planning land management and transportation-related activities on a geographic and temporal basis in the presence of multiple and sometimes conflicting objectives (Zuuring and others 1995). These models permit land managers to predict vegetation change over landscapes, change in the probability of disturbance processes relative to vegetation change, and future effects on resource values.

The Approach

Although some analysts using a single modeling system approach have addressed these problems, we have chosen to use two landscape modeling systems that are integrated for project planning purposes. A simulator and an optimizer are used and executed as separate entities that share information between them. In this way the analyst uses the strengths of both modeling systems (*fig. 1*).

The process begins by using SIMPPLLE to project the frequency and location of natural disturbances for the "no action" management alternative with fire suppression. These results are then used to compute a risk index for each stand on the basis of the most likely type of disturbance and the probability of its occurrence. This index is incorporated into a management relation, built in MAGIS, to evaluate fuel treatments and their economic payoffs. Additional management relations that together comprise a planning scenario handle other issues. Examples of such relations are acres in various stand size classes, equivalent clear cut acres by watershed, sediment production by watershed, big game hiding cover by third order drainage, pine marten habitat index by third order drainage, and net revenues from several accounting stances. Amounts are calculated for these management relations when MAGIS is run in either simulation mode (managers choose the location and timing of activities) or optimization mode (the solution process chooses the timing and location of activities on the basis of the stated objectives). In a fuel treatment situation the analyst is usually interested in minimizing a risk index subject to a set of constraining management relations while attaining a reasonable net revenue

Figure 1
Analysis approach that uses the strengths of both modeling systems: simulating vegetative patterns and processes at landscape scales (SIMPPLLE) and multi-resource analysis and geographic information system (MAGIS).



(not maximized but costs are at least covered by revenues). The solution yields outputs in the form of stand acres that are multiplied by their corresponding risk index and summed over all stands. In this manner a number of alternative planning scenarios, each consisting of a series of treatments applied over time and space, can be compared (on the basis of certain criteria) to identify those alternatives that reduce or eliminate the risk. The schedule of activities proposed by MAGIS is imported into SIMPPLLE where additional simulations are run to evaluate the changes in location and extent of disturbances associated with these activities.

Methods

The sequential approach of applying SIMPPLLE and MAGIS was applied on the 58,084-acre Stevensville West Central area of the Bitterroot National Forest in Montana. SIMPPLLE and MAGIS applications were initially developed in cooperation with Forest staff and applied in an integrated resource analysis of that area (USDA Forest Service 1996b). The area modeled includes 25,284 acres in the Selway-Bitterroot Wilderness, 14,155 acres of National Forest outside Wilderness, and 18,645 acres in private ownerships. No treatments were proposed for the private land. It was instead included to capture interactions in functions and processes with adjacent National Forest lands.

The first step was to run stochastic simulations of SIMPPLLE over 5 decades for the "no action" management alternative with fire suppression. The number of acres impacted by four specific natural processes and their associated frequencies of occurrence in stands located across the landscape were computed. These four processes were stand-replacement fire, mixed-severity fire, light-severity fire, and western spruce budworm.

A risk index was developed to capture the relative importance of various natural processes and their frequency. This index can be thought of as a measure of undesirability of these processes, or alternatively, a prioritization for the application of fuel treatments. The weights assigned to this risk index are:

Weight value	Risk source	Frequency of source
0	Stand not listed	
2	Light spruce budworm	≥ 50 pct
2	Mountain pine beetle	≥ 50 pct
4	Low probability of stand replacing fire	1 - 10 pct
6	Severe spruce budworm	≥ 50 pct
8	Moderate probability of stand replacing fire	11 - 20 pct
10	High probability of stand replacing fire	≥ 20 pct

The distribution of these index weights was determined on the basis of the frequency of these processes on the landscape (*fig. 2*). For each stand, risk index weights were entered into MAGIS, and a risk index management relation was constructed. This risk index management relation multiplies the risk index assigned to the stand by the stand acres and sums this product across the stands as follows:

$$\text{Risk index management relation} = \sum_a \sum_s \sum_p r_{asp} * X_{asp}$$

in which:

X_{asp} = Treatment option a applied to stand s in decade p ,

r_{asp} = Risk index value in decade p as a result of applying treatment option a to stand s . For "no action," r_{asp} equals the index assigned by SIMPPLLE. If a treatment is undertaken that addresses the risk, r_{asp} after treatment is reduced accordingly.

Table 1—Specifications for four fuel treatment scenarios for the Stevensville West Central area on the Bitterroot National Forest, Montana.

Issue	Scenario			
	1	2	3	4
Prescribed fire permitted in Wilderness	X	X		
Minimum risk index in decade 1	X		X	
Minimum risk index in decade 3		X		X
Water yield limits			X	X
Sediment yield limits			X	X
Harvest volume per decade < 10,000 CCF	X	X	X	X

The next step was to run MAGIS in simulation mode to compute the risk index management relation value for the "no action" alternative. MAGIS was then used to develop four fuel treatment scenarios for the landscape (*table 1*).

Scenarios 1 and 2 both permit prescribed burning in the Wilderness area. They differ in that Scenario 1 requires the risk index to be minimized in decade 1, while the timing is relaxed in Scenario 2 to minimize risk by decade 3. Fuel treatments for Scenarios 3 and 4 are limited to the 14,155 acres of National Forest outside the Wilderness, and water and sediment yields were limited to Forest Plan direction in six individual watersheds. Like the first two scenarios, Scenarios 3 and 4 differ by the decade for minimizing risk index: decade 1 for Scenario 3 and decade 3 for Scenario 4. All four scenarios limited the volume of timber harvest per decade to 10,000 CCF or less, assuming that larger harvests would be politically unacceptable.

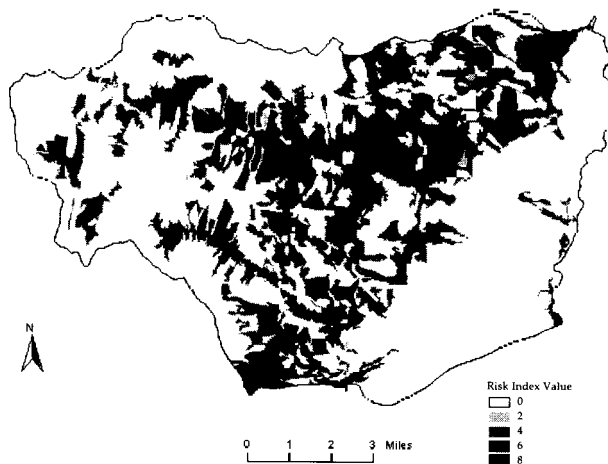
Each scenario was solved by first minimizing the risk index management relation for the specified decade, then achieving a second solution in which present net value was maximized while holding that risk index management relation to an amount slightly above the previously attained minimum value. The other conditions for the scenarios (*table 1*) were in effect in these solutions. This sequence develops an economically efficient scenario for minimizing risk while meeting the other scenario conditions. These solutions schedule treatments both spatially and temporally (*fig. 3*).

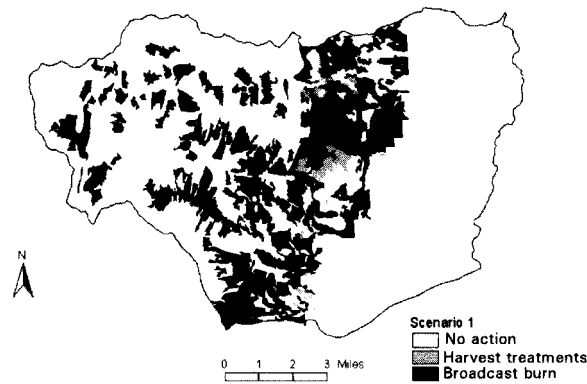
Results

The results pertaining to the four scenarios and the "no action" alternative were determined (*table 2*). The risk index associated with the "no action" alternative was 93,196. Scenario 1 reduced the risk index to 26,000 in decade 1, but with a net cost of \$2,518,000. This scenario contained 14,856 acres of broadcast burning in decade 1, as well as fuel treatments involving 306 partial cut and 298 regeneration cut acres that resulted in commercial timber harvests. Postponing the minimization of the risk index until decade 3 (Scenario 2) resulted in a positive

Figure 2

The spatial distribution of risk index based on natural processes occurring over 5 decades.



**Figure 3**

The spatial distribution of decade 1 burning and harvesting fuel treatments for Scenario 1.

present net value of \$148,000 associated with the treatments. When the broadcast burning was postponed until decade 3, the treated area was reduced by 1,145 acres as compared to Scenario 1.

For Scenarios 3 and 4 where fuel treatments are limited to only the public non-Wilderness area, the risk index was reduced to 52,000. Broadcast burning reduced to 8,525 in decade 1 for Scenario 3 and to 7,556 acres in decade 3 for Scenario 4. Acres of fuel treatments involving timber harvests for Scenarios 3 and 4 approximated those for Scenarios 1 and 2. The fewer prescribed burning acres resulted in an improved financial situation with present net values, \$-608,000 for Scenario 3 and \$979,000 for Scenario 4.

Next, the four management scenarios were entered into SIMPPLLE to model the effect of these treatment schedules on acres of stand-replacing fire (SRF), mixed-severity fire (MSF), light-severity fire (LSF), and western spruce budworm (WSBW), as well as the net effect on smoke production, and fire suppression costs. Twenty simulations were run for 5 decades for each scenario. For SRF, the pattern over the 5 decades for Scenarios 1 and 3 is similar to "no action," but with about 200 fewer acres burned on the average (*fig. 4*). For Scenarios 2 and 4, SRF acres are initially higher than "no action," decrease substantially for decades 2-4,

Table 2-Summary of solution amounts for selected management relations "no action" and Scenarios 1 - 4.

Management relation	Units	No Action	Scenario			
			1	2	3	4
Present net value ¹	\$1000	0	-2,518	148	-608	979
Risk index for decade 1	Index	93,196	26,000	90,637	52,000	91,042
Risk index for decade 3	Index	93,196	25,918	26,000	52,000	52,000
Harvest volume-decade 1	CCF	0	7,872	10,000	10,000	10,000
Harvest volume-decade 2	CCF	0	0	6,746	489	8,463
Harvest volume-decade 3	CCF	0	4,659	3,301	7,269	3,562
Under-burning-decade 1	Acres	0	0	0	24	15
Under-burning-decade 2	Acres	0	0	0	0	0
Under-burning-decade 3	Acres	0	0	0	0	0
Broadcast burning-decade 1	Acres	0	14,856	0	8,526	0
Broadcast burning-decade 2	Acres	0	0	0	0	0
Broadcast burning-decade 3	Acres	0	0	13,711	0	7,556
Pre-commercial thin-decade 1	Acres	0	34	34	34	34
Pre-commercial thin-decade 2	Acres	0	0	0	0	0
Pre-commercial thin-decade 3	Acres	0	0	0	0	0
Partial cuts-decade 1	Acres	0	306	1,240	306	1,068
Partial cuts-decade 2	Acres	0	0	105	0	105
Partial cuts-decade 3	Acres	0	0	0	0	0
Regeneration cuts-decade 1	Acres	0	298	27	401	83
Regeneration cuts-decade 2	Acres	0	0	374	32	510
Regeneration cuts-decade 3	Acres	0	213	27	324	27

¹Discounted at 4 percent.

and then level off. Scenarios 1 and 2, which treat Wilderness acres, result in fewer acres of SRF from decades 3-5.

For MSF, all the fuel treatment scenarios showed about the same number of acres in decade 1 as "no action" (fig. 5). After decade 1, Scenario 1 showed the most reduction in acres burned relative to "no action" and remained among the lowest over the 5 decades. Scenarios 3 and 4 also showed fewer acres burned, with acres burned over the 5 decades varying between "no action" and Scenario 1. Interestingly, Scenario 2, which rose above "no action" in burned acres in decade 2, eventually had the fewest MSF acres by decade 5. For LSF, the pattern of fire associated with fuel treatment scenarios was dependent on whether risk was minimized in decade 1 or 3 (fig. 6). For Scenarios 1 and 3 (minimize risk in decade 1) the burned acres were very low, but increased to the "no action" acres by decades 2 and 3. For Scenarios 2 and 4 (minimize risk in decade 3), the initial LSF acres exceeded "no action," dropped to almost zero by decade 3, then increased to approximate "no action" by period 4.

With regard to severe WSBW, Scenarios 1 and 3 (minimize risk in decade 1) showed a sharp decrease in the mean number of acres infested in decades 1 to 3 relative to "no action" (fig. 7). Scenarios 2 and 4 (minimize risk in decade 3) began with the number of infested acres only slightly less than "no action," but decreased to approximate the low level of severe WSBW of the other scenarios by decade 3. Severe WSBW remained low for all scenarios after decade 3.

Figure 4

Estimated mean number of acres affected by stand-replacement fire over 5 decades

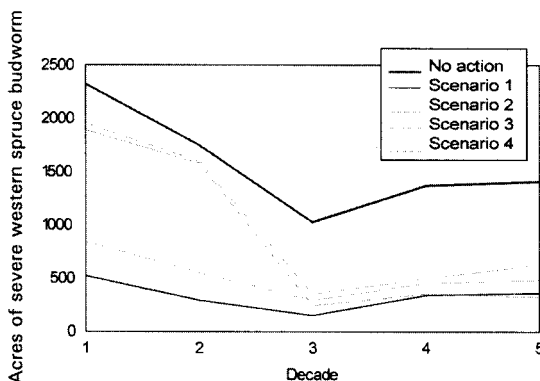


Figure 5

Estimated mean number of acres affected by mixed-severity fire over 5 decades.

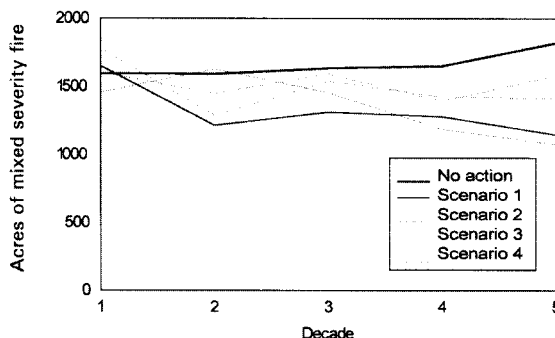
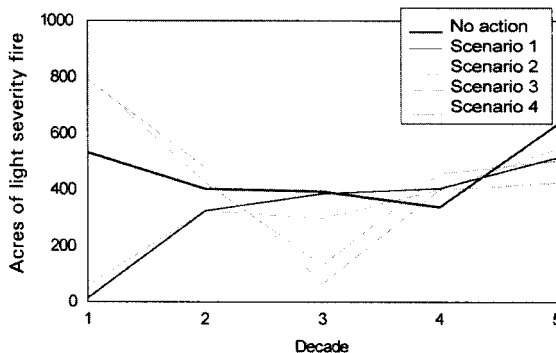
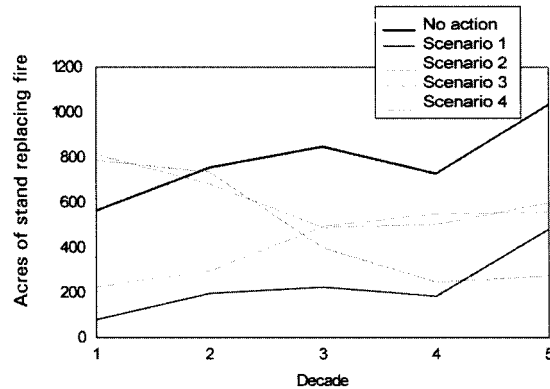


Figure 6

Estimated mean number of acres affected by light-severity fire over 5 decades



**Figure 7**

Estimated mean number of acres affected by severe western spruce budworm over 5 decades.

Discussion

Several trends were observed from the four treatment scenarios. As might be expected, substantially fewer acres of the modeled natural processes were occurring in the initial decade for the scenarios where risk was minimized in decade 1 (Scenarios 1 and 3). The scenarios with risk minimized for decade 3 (Scenario 2 and 4), however, were approaching Scenarios 1 and 3 by decade 3 for most processes.

The scenarios having fuel treatments applied in Wilderness (Scenarios 1 and 2) did result in fewer total acres of undesirable natural processes over the 5 decades. The differences were most distinct for stand-replacing fire and mixed-severity fire, and minor for light-severity fire and severe western spruce budworm. It is interesting to note that by decade 5, Scenario 2 had the fewest acres for each of the four modeled natural processes.

The difference in net fuel treatment cost was substantial between the scenarios minimizing risk in decade 1 versus decade 3. The difference was that minimizing risk in the later decade provided the opportunity to implement more fuel treatments in the form of commercial timber harvests. This provided revenue that offset costs to result in positive net revenues for fuel treatments in Scenarios 2 and 4.

More fuel treatment scenarios could be developed for the Stevensville West Central area and the trade-offs could be measured in terms of costs and reductions in acres affected by various processes. The real value of this and other modeling approaches is to identify and measure trade-offs so that more informed decisions are possible. The integration of simulation and optimization models such as SIMPPLLE and MAGIS have great potential for developing spatially-specific fuel treatment scenarios for landscapes and effectively quantifying the trade-offs associated with those scenarios. This provides the opportunity to better understand, manage, and monitor forested landscapes.

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An Analytical Approach for Assessing Cost-Effectiveness of Landscape Prescribed Fires¹

Philip N. Omi,² Douglas B. Rideout,² Stephen J. Botti³

Abstract

Analytical tools are needed for assessing the cost and effectiveness of large-scale prescribed fire programs. Cost and effectiveness trade-offs for U.S. Department of Interior (USDI) fuels treatment programs were analyzed, with particular emphasis on National Park Service (NPS) hazard fuel reduction projects. A prototype simulation model was developed for the Mineral King study area in Sequoia-Kings Canyon National Parks (SEKI), California. Our prototype process used the FARSITE™ simulator to examine fire size and intensity (with and without fuel treatment) to develop a cost-effectiveness frontier. Managers can use this frontier to select the most effective fuel treatment strategy subject to the available budget. Other trade-offs can be examined by transforming simulator outputs (e.g., fuel treatment expenses versus suppression cost savings).

Hazardous fuels have built up on many U.S. Department of Interior (USDI) lands as a result of cultural and ecological processes. Although USDI bureaus (National Park Service, Bureau of Land Management [BLM], Fish and Wildlife Service, and Bureau of Indian Affairs) have reduced fuels through prescribed burning and mechanical manipulation for many years, data are still lacking relating treatment prescriptions to reductions in wildfire risks and hazards. Agencies also lack the ability to identify the most cost-effective fuel treatment for a given budget.

Our project has focused on development of a cost-effectiveness analysis (CEA) system for USDI hazard fuels reduction programs (Omi and others 1998). Analysis tools are needed that will enable the USDI to model the effectiveness of incremental increases to hazard fuel reduction funding in terms of protecting resources at risk, reducing wildfire suppression costs, and restoring natural ecosystems.

Assessing the cost-effectiveness of fuel treatments presents many challenges. These challenges are accentuated when the fuel treatment under consideration is prescribed fire, especially when proposed fires will be applied over a large geographic area such as a watershed. Anecdotal evidence may point to prescribed fire as the fuel treatment of choice for an area, especially in areas managed for ecosystem sustainability or restoration of natural patterns and processes. However, analytical tools are needed for justifying the appropriate level of fire application for an area. Although prescribed fire treatments generally are lower in cost than other fuel treatments (i.e., mechanical thinning, fire also is more variable in its effects; Omi and Kalabokidis 1998). This variability in treatment effect is especially evident (and often desired) in the spatial mosaic created by large-scale fire applications. Further, mechanical methods may not be suitable where land management objectives call for restoring or imitating natural patterns and processes over the landscape, such as in a national park.

This paper summarizes initial efforts aimed at constructing a prototype cost effectiveness simulator for the Mineral King study area in Sequoia-Kings Canyon National Parks (SEKI), California.

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Policy, and Planning: Bottom Lines, April 5-9, 1999 in San Diego, California.

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Methods

Initially we hoped to rely on the existing USDI 1202 database of historical fires to obtain cost and effectiveness estimates. We had hoped that historical evidence would confirm that prescribed fire had reduced wildfire frequency and management costs. When the data proved to be of questionable quality, we relied on a survey of fire managers to provide estimates for fuel load reductions made possible by prescribed fire treatments. These estimates were used to construct custom fuel models representing fuelbeds after treatment for running the FARSITE™ model⁴ (Finney 1998).

For the prototype simulation four wildfires were ignited on an untreated landscape and allowed to burn for 12 hours. Fuel treatment levels were simulated by considering the different statistical combinations of four segments or zones that could be treated in the potential path of wildfires in the Mineral King watershed (i.e., a total of 15 potential treatment levels and one control or untreated level). To simulate fire spread after treatment, the four wildfires were re-ignited in the same locations and allowed to burn for the same time periods. Fire behavior outputs from all runs were saved in column-delimited format for export into a spreadsheet file. Fire behavior outputs compared included fireline intensity and size.

Acres burned by wildfires after treatment were subtracted from acres burned before treatment, yielding acres reduced. Historical costs for BLM suppressed fires (Omi and others 1995) were used to determine the costs of wildfires. RXCOST (Omi and others 1992) was used to determine cost of the treatments. Prescribed fire costs for treating fuel segments plus subsequent wildfire costs were added together and compared to the wildfire cost without any treatment. Cost and effectiveness tradeoffs between different levels of fuel treatments were assessed graphically.

Results

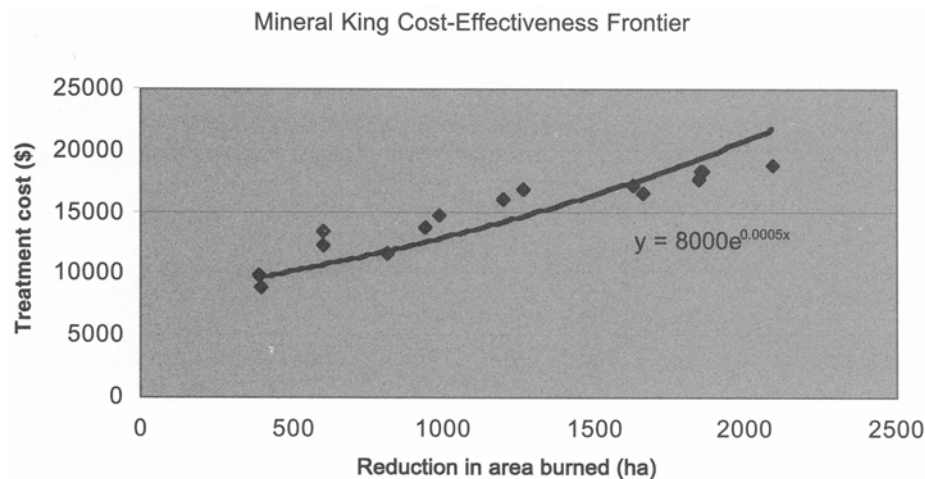
The simulation results from the 15 treatment combinations were summarized, including reductions in area burned and (treatment plus suppression) cost savings, with and without treatment (*table 1*). Simulated burned area reductions ranged from 391 to 2,092 ha with approximated cost reductions from about \$8,000 to \$62,000.

Table 1-Summary of treatment combinations and outcomes for the Mineral King study area, Sequoia-Kings Canyon National Park.¹

Treatment	Area treated (ha)	Treatment cost (\$)	Reduction in area burned (ha)	Cost difference (\$)
1	2,348	\$16,008	1,196	\$31,704
1,2	2,810	\$16,934	1,264	\$33,283
1,2,3	3,781	\$18,400	1,849	\$58,507
1,2,3,4	4,105	\$18,860	2,092	\$62,059
1,2,4	3,134	\$17,145	1,628	\$46,560
2	462	\$9,929	391	\$7,967
2,3	1,433	\$13,877	940	\$24,337
2,4	785	\$11,621	813	\$21,889
2,3,4	1,757	\$14,713	988	\$25,283
3	972	\$12,360	603	\$13,383
3,4	1,296	\$13,472	600	\$12,140
1,3	3,320	\$17,712	1,846	\$54,082
1,3,4	3,644	\$18,270	1,859	\$54,015
4	324	\$8,952	396	\$9,096
1,4	2,672	\$16,632	1,658	\$48,199

⁴Mention of trade names or product is for information only and does not imply endorsement by the U.S. Department of Agriculture.

¹Estimates based on FARSITE™ simulations with and without fuel treatment, and cost estimates from Omi and others (1992, 1995).

**Figure 1**

Cost-effectiveness frontier for large-scale prescribed fire treatments, Mineral King watershed, Sequoia-Kings Canyon National Park, based on FARSITE™ simulations, with and without fuel treatment.

Results were analyzed graphically (*fig. 1*). The "cost-effectiveness frontier" identifies the trace of greatest reductions in burned area per dollar spent in fuel treatment. In this example one point on this path involves treatment of segment 4 with a cost of \$8,952 and burned area reduction of 396 ha (table 1). Alternatively, a manager could treat segments 2 and 4 for a cost of \$11,621 and realize a burned area reduction of 813 ha; or he/she could treat segments 1 and 4 for a cost of \$16,632 and burned area reduction of 1,658 ha. The most expensive alternative, treatment of all segments (1-4), would cost \$18,860 and reduce burned area by 2,092 ha. Treatment levels interior to the frontier are less cost-effective.

Further, with a limited budget the most cost-effective treatment combination will be that which lies on the frontier and fits within the funding constraint. In this example, if the decision-maker had a fuel treatment budget of \$12,000, the best treatment combination would be segments 2 and 4. With a \$19,000 budget, the most cost-effective decision would be to treat all four segments. Thus, the choice of treatment alternative is left to the manager, and the cost-effectiveness frontier with the budgetary constraint identifies the best choice.

Treatment and suppression cost savings with the different alternatives were identified (*table 1*). These can be graphed and analyzed similarly, along with other outputs from the simulation, e.g., reductions in fire intensity.

Discussion

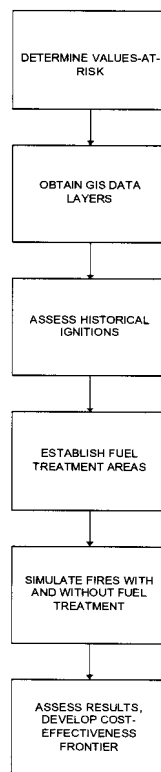
Construction of the prototype yielded considerable insight into problems associated with simulating cost-effectiveness in the Mineral King study area. Although the prototype was restricted to four fires burning into four treated segments, we were able to demonstrate the feasibility of the process.

Results from the FARSITE™ runs indicate that it is possible to establish a cost-effectiveness frontier for a fuels treatment program involving large-scale prescribed fires. Inferences derived from considering fire area are more reliable than intensity data, but problems with intensity measurements will be addressed in the second phase of this project. Other prescribed fire outcomes that should also be considered include smoke emissions, effects on nonmarket resource, and probability of escape.

A more comprehensive framework for evaluating a prescribed fire program can be designed (*fig. 2*). Precise estimates for values-at-risk incorporated in a geographic information system (GIS) may not be needed for our analysis if we identify their spatial location. Further, our work on this prototype suggests that fuel treatments can be analyzed relative to other meaningful indicators (e.g., suppression cost savings, changes in smoke emissions, or any other outcome where estimates are available with and without fuel treatment).

Figure 2

Flow chart for prototype cost-effectiveness simulator.



Conclusions

The first phase of this project has assessed problems and established the feasibility of carrying out a cost-effectiveness analysis of hazard fuel reduction programs. The project addressed general issues related to conducting a cost effectiveness analysis, limitations of available databases, and restrictions resulting from incomplete understanding of fire behavior, especially large-scale landscape fires. The feasibility of conducting a cost-effectiveness analysis was addressed through the development of a prototype simulator, based on the FARSITETM simulator with and without fuel treatments proposed for the Mineral King study area. The Mineral King study provides a good test for the prototype because of its fire history, fuel profiles, and ongoing experimentation with large-scale prescribed fires. The prototype's greatest applicability will be to assess areas with aggressive fuel treatment programs, such as Mineral King. However, the methods developed during this project may have broader applicability if analysis units maintain good records on historic fires and fuel treatments. Continued improvement in GIS-based inventories will also refine our prototype's capabilities.

Acknowledgments

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Prescribed Mosaic Burning in California Chaparral¹

Richard A. Minnich,² Ernesto Franco-Vizcaíno³

Abstract

In fire-prone ecosystems, knowledge of previous fire history and long-term fire regimes is essential to the establishment of ecologically sound fire management. In the Californian chaparral, fire regimes are determined by the rate of fuel accumulation and previous fire history. The evolution of patch mosaics created by fire is a non-random and self-organizing process because the occurrence of fire events is affected by past events, and in turn affects future events. A strategy that increases the frequency of burns (events/area) on the landscape can reduce the probability of large fires by establishing a highly fragmented patch structure. Baja California's chaparral has a highly fragmented patch structure that is resistant to the spread of large fires. Because it is an example of ecosystems functioning under natural disturbance, it should be used as a model for fire management in California.

In fire-prone ecosystems, knowledge of previous fire history and long-term generic fire regimes (fire intervals, intensities, size, weather) is essential in the evaluation of relationships between fire and vegetation dynamics, as well as in the establishment of ecologically sound fire management. In the California chaparral, the fire regime is characterized by a self-organizing patch dynamics, making the vegetation an ideal setting for proactive broadcast planned burning for fuel management. A strategy that increases the frequency of burns (events/area) on the landscape can reduce the probability of large fires by establishing a high degree of fragmentation in patch structure.

These findings emanate from the profound discontinuity in land-use and fire history along the United States-Mexican boundary (Minnich 1983, Minnich and Chou 1997). In the United States, anthropogenic control of fire has been in place for a century, whereas little or no fire control has occurred in the isolated wildlands of northern Baja California. On the Mexican side of the international boundary, the chaparral appears as a diverse, fine-grained patch mosaic. From any view, a dozen patches of different ages may be seen---from fresh burns, to medium-sized stands, to dense old-growth stands. Beneath distant smoke columns are fires creeping through the brush with discontinuous lines of flames less than 5 m in length. North of the international boundary, however, the mountains support unbroken, dense, old-growth chaparral interspersed by a few extensively denuded watersheds from a fire provoked by a past Santa Ana wind.

This paper discusses the process by which a superior chaparral landscape has developed in Baja California without fire management.

Self-regulating Fire Regime

In the Californian chaparral, the fire regime is constrained in time and space by the rate of fuel accumulation and previous fire history (Minnich and Chou 1997). Although the standing biomass is high (40 to 100 tons per hectare), the flammability of stands remains low during the first decades of succession because of low fuel continuity (stand cover) and biomass, as well as high stand fuel moisture due to low dead-to-live stand fuel ratios. Fuels tend to be moist because the evergreen shrubs have good stomatal controls, and evapotranspiration rates are low despite high evaporative demand. This efficient internal water regulation, coupled with low annual biomass production tend to reduce interannual

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variability of fire hazard and fire recurrence intervals. Because fire hazard develops gradually, preventing the recurrence of fire far into the successional cycle, fire probability is heterogeneous from stand to stand, depending upon the differential fuel build-up related to previous fire history. Thus, the evolution of patch mosaics created by fire is a non-random and self-organizing process because the occurrence of fire events is affected by past events, and in turn affects future events. Fires burn mostly old stands (> 40 years), and the spatial extent of burns is limited by surrounding younger stands that have lower fire probability. The steady fuel build-up also results in temporally uniform, long fire intervals and a steady rate of burning at the scale of the landscape, especially over multiple fire cycles. As a consequence, there is an inverse relationship between fire frequency (events/ area, or event density) and fire size.

Baja California fires have been small because historically high burn densities have resulted in a fragmented patch structure that precludes large fires. Conversely, in California, control of fires has resulted in low fire densities and extensive stands of mature chaparral. Fires are few and large, and they spread at intensities beyond the ability of fire management agencies to suppress them.

Effects of Fire Suppression

Reversing this dilemma of large fires in California requires understanding the specific impacts of suppression. The objective of fire management in chaparral has been to put out all fires as soon as possible. Small fires were extinguished by small fire crews with portable equipment, or so-called "initial attack." Because 99 percent of fires are put out in initial attack (mostly at < 1 hectare), the few fires that do escape this phase of suppression invariably grow into intense fires of enormous size (10,000 to 60,000 hectares). The management objective for large fires is to surround the flame lines with men and equipment. In an intense, fast-moving brushfire, most effort is placed upon the protection of structures in the path of the flames. These costly efforts have little effect on fire spread, as evidenced by the much larger fires in the chaparral of California than Baja California, where large fires are not fought. The efficiency of the "initial attack" practice greatly diminishes the number of moderate sized burns (about 500 to 3,000 hectares), and encourages stand homogenization. Fires can spread as far as the heavy fuels can support them.

The most significant and negative impact of suppression is that efficient "initial attack" selects for large fires to occur during the severe fire weather. In Baja California, fires are temporally random and most events, even moderate-size fires of 500 to 2,000 hectare fires, take place in weather that occurs most frequently within the climatic distribution. The majority of fires burn slowly in summer afternoons with westerly slope winds of 5 to 10 meters sec⁻¹, temperatures of 30 to 35°C, and relative humidity of 20 to 40 percent. Because of the effectiveness of initial attack in suppressing fire starts in normal weather, large fires in California coincide with low relative humidity (≤ 20 percent) and high winds of 35 to 80 kilometers hour⁻¹, notably Santa Ana winds and "sundowner" winds, which accelerate flame spread and fuel consumption rates, as well as producing longer flame lengths.

Historically, the development of fire management has been a response to the threat of fire to land-use and watershed. Thus, suppression is fundamentally "reactive" and cannot be reconciled with fire as a natural process. Focussing on extinguishing of burns fails to address the management of regional vegetation and stand homogenization. The concept that surrounding burns can prevent the destruction of infrastructure is illogical when fire suppression forces cannot control large fires. The energy of flame lines is several orders of magnitude greater than the energy expended to put them out, and this overwhelms the ability of fire fighting forces to protect property and resources.

Fire Regime Properties Useful to Management

Examination of the fire history in chaparral of California and Baja California (Minnich and Chou 1997) leads us to several fundamental conclusions that are vital in fire management. First, fire poses only a cyclical threat in space and time. The removal of fuels by fire precludes the occurrence of another fire until there has been sufficient development of vegetation and fuels after fire (plant succession). In addition, at short time scales of days when fires are spreading, only a discrete portion of the vegetation (old stands) is flammable, as defined by a combustion threshold (CT) related to stand age; remaining younger stands are not flammable (Minnich and Chou 1997). The growth of vegetation and fuel production is nearly constant, reflecting the broad-scale climate. Therefore, the spatial extent of burning will approach steady-states averaged over long time scales, and at the scale of the landscape.

Another factor for management is that fire rotation periods in southern California and Mexico are very similar. Hence, suppression has not resulted in excessive regional fuel build-up. As a corollary, suppression will not slow down the pace of burning. In addition, the size of individual fires is inversely related to the density of fire events. Increasing the number of fires will produce smaller fires but not an increase in the area burned. Vegetation cannot be burned at higher rates because the availability of fuels becomes more limiting (an increase in the area of nonflammable vegetation). Finally, without fire control, high fire densities and fine-grained patch mosaics are a spontaneous outcome due to high natural ignition rates. A corollary of this is that the suppression of fires has reduced fire frequencies.

Broadcast Mosaic Burning

Although wildland fires present the greatest threat to communities at the urban-wildland interface, the most intractable problem has been the growth of the dispersed, small land-holdings within wildlands, whose presence complicate broadscale regional fire management. A management solution to this problem permits the development of a strategy that also furnishes protection at the urban-wildland interface.

Instead of encircling fires, an alternative policy is to treat settlement inholdings (ranchsteads, villages, camping facilities) as point features, around which fires can be allowed to pass through in a vast cyclically flammable landscape. For this strategy to work, there must be intense fuel management around local inholdings. In Baja California, local ranches use cattle, goats, or other livestock to remove fuels around buildings. Agricultural zones and cities use livestock, or plow fields in contact with natural vegetation. Similar measures can be undertaken in California, including severe building codes that require the design of fire proof structures. Once inholdings are made "fire safe" with these mitigations, fuel management through maintenance of a patch mosaic in the natural vegetation can be accomplished through the use of planned broadcast burns of moderate size. Patch structure can play the role of an "insurance policy" to plan the location and size of future burns, i.e., flame lines spread across old-growth patches with prevailing winds until they are controlled by young stands down-wind that lack sufficient fuel to sustain flames. Fire fighting personnel need only to check the progress of the fire relative to the preexisting patch mosaic. This strategy can be accomplished by recycling chaparral at intervals of 50 years. This is seen in Baja California where relatively old stands can still restrain fires burning in still older stands due to prevailing low fire intensities. Other advantages of planned broadcast mosaic burning include the proactive selection of appropriate weather and the forewarning of landholders weeks in advance.

To design specific management plans, National Forests and other land management agencies already have fire history databases to reconstruct current patch structure. The primary advantage of prescribed broadcast mosaic burning is that moderate size units of vegetation (about 500 to 2,000 ha) can be burned economically. However, this will be effective only if planned burns remove fuels at the same rate that fuels build up. This requirement is actually modest. For example, in the San Gabriel Mountains of California there are about 250,000 hectares of chaparral. To completely recycle the entire ecosystem at 40-year fire return intervals requires that an average of 6,250 ha are burned each year. This is equivalent to only two or three burns a year.

In California, prescribed burns are mostly small in scale (< 40 hectares). They are used mostly to remove fuels adjacent to structures, or in the urban/wildland interface, and are therefore prohibitively expensive. Moreover, the cumulative area of prescribed burns is perhaps two orders of magnitude below that required to keep up with regional fuel build up.

Planned burns should also be conducted during the summer, which is the primary fire season in Baja California. The weather is fairly constant, dominated by upslope winds in daylight and downslope air drainage at night. Unexpected weather conditions as a result of the jet stream (such as Santa Ana winds) are practically nonexistent, especially in July and August. In our experience of past fires, flames normally spread slowly uphill during afternoons. Flames generally stop during the night, with fires persisting in logs, snags, and root burls. The implementation of planned burns during normal weather reduces the potential for uncontrolled fires in extreme weather.

Conclusion

In fire management, it is perhaps not the best advice to produce a fire management system based on observations of a typical backyard. The fire history in California is a sad story of one conflagration after another. Yet, this has been our entire experience because we know little of the chaparral fire regime before fire control. In establishing a fire management system, it is important to examine the "well-managed" status of chaparral in Baja California as a example of ecosystems functioning under natural disturbance.

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Restoring Fire to Southwestern Ecosystems: Is It Worth It?¹

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Abstract

The historical record supported by tree ring analysis indicates that fire played a dominant role in pre-settlement southwestern vegetation types within Arizona and New Mexico. Studies within some of these vegetative types have indicated a frequent natural fire interval. As early settlers built homes and businesses adjacent to these forested areas, they quickly recognized fire as a threat to their livelihood. This wildland fire (new terminology from Implementation Procedures Reference Guide) threat has been dealt with effectively for the past 100 years by aggressive fire suppression. Without fire, ecosystem health began changing. Forest fuels have increased that were once recycled by frequent surface fires. As a result fire size and intensity as well as suppression costs have increased. The use of wildland and prescribed fire over time will improve ecosystem health and reduce the suppression costs of unnecessary wildland fire. The cost of returning fire to some areas will be high; therefore, we must evaluate the risk involved if nothing is done.

Introduction

The role of fire, before European settlement, including fire frequencies, within many ponderosa pine (*Pinus ponderosa* Dougl. ex laws) forests of the Southwest is well-documented (Covington and Moore 1994a, Moir and Deiterich 1988, Moody and others 1992, Swetnam and others 1990). These studies emphasize that fire has maintained an open parklike forest structure with a characteristic herbaceous understory (although some studies have suggested an alternate view [Shinneman and Baker 1997]). Heavy livestock grazing during the late 1800's, followed by aggressive fire suppression and accelerated logging, altered forests from open parks consisting of single-storied stands with a continuous bunchgrass understory cover to multistoried stands with dense downed-woody material and sparse live ground cover (Covington and Moore 1994a). Areas within the Gila Wilderness, on the Gila National Forest in southwestern New Mexico (fig. 1) still maintain these characteristics (Boucher and Moody [In press]).

Before to the late 1800's, these frequent low-intensity surface fires helped to maintain a ponderosa pine and Gambel oak (*Quercus gambelii*) forest on xerophytic sites. Ponderosa pine, Douglas-fir (*Pseudotsuga menziesii*), and Gambel oak occupied moister sites (Moir and others 1997). Ground cover was a continuous grass savanna comprised of Arizona rescue (*Fistula Arizona*) and mountain mule (*Muhlenbergia montana*) on the Mogollon Plateau in Arizona and New Mexico, and screw-leaf muly (*Muhlenbergia virescens*) on pine-covered mesas within the Gila Wilderness. These grasses become dormant during the dry periods of May and June. The accumulated leaf biomass of several fire-free years provided fine fuels to carry low-intensity ground fires with little damage to the parent plant. These grasses recover quickly with the arrival of moisture from the tropics during the summer monsoon period. The herbaceous component was thought to have been fairly continuous, growing up to and against the trunks of trees (Baisan and Swetnam 1990; Barton 1995; Caprio and Zwolinski 1995; Deiterich and Hibbert 1990; Fule and Covington 1994, Grissino-Myers and others 1995; Moir 1992, Swetnam and others 1992, 1995, 1996; Villanueva-Diaz and McPherson 1995).

Tree ring analysis of burn scars has been used to estimate fire frequencies within the mesophytic and xerophytic stands of ponderosa pine in the Southwest (Moir and others 1997, Swetnam 1990). It is generally accepted that fire occurred

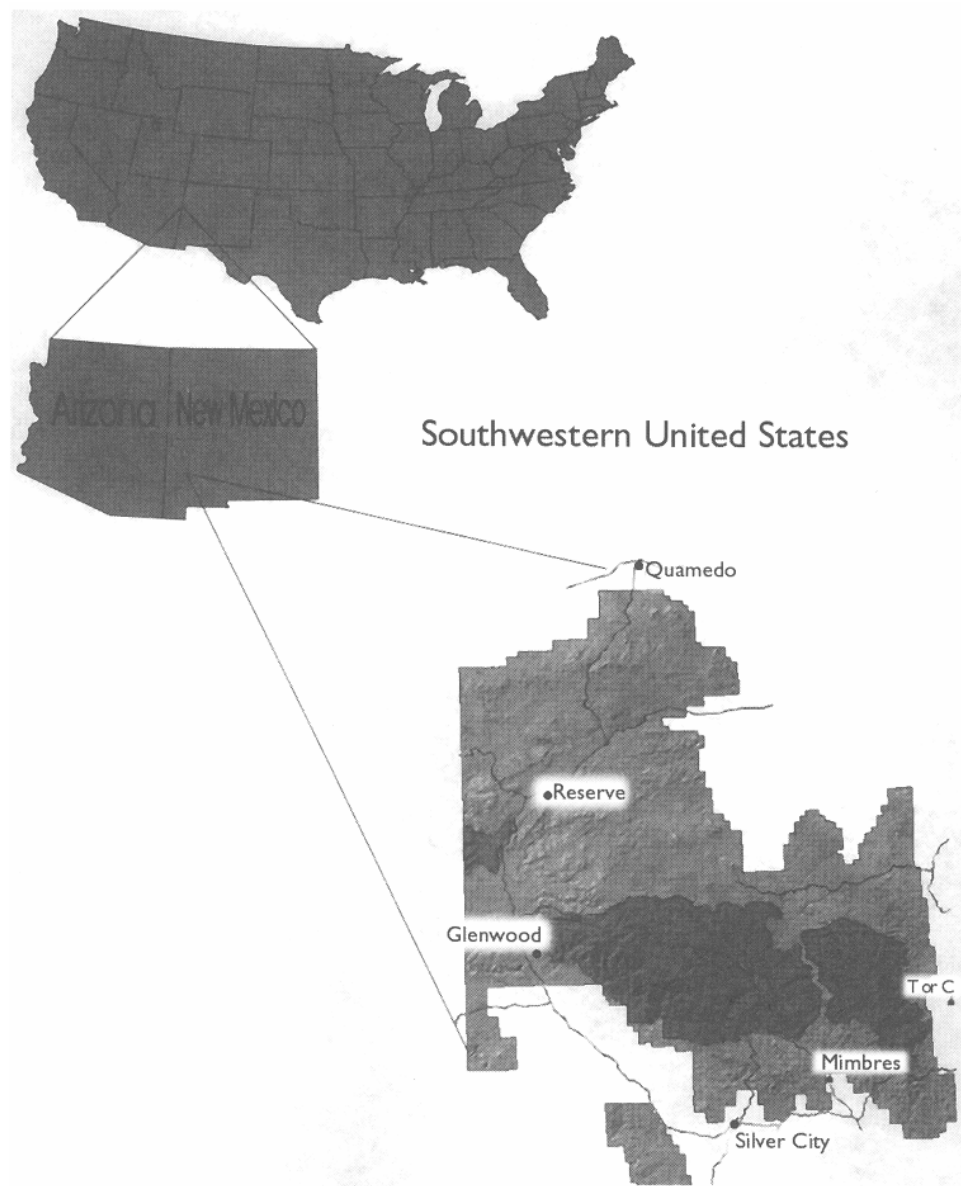
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Figure 1

Gila National Forest and
Wilderness Area.



on 2- to 12-year intervals for the xerophytic sites and up to 15 years for mesophytic sites (Cooper 1961, Covington and Moore 1994a, White 1985). Stand-replacement crown fires were considered rare and were typically confined to small thickets when they occurred (Pyne 1996, Woolsey 1911). Because of these frequent fire events, it is believed that the species of plants and animals within this vegetation type have evolved with fire. It is also quite possible that they or their habitats require frequent fires to remain viable. Much remains unknown about the soil microbial community and their interdependence with fire (Boucher and Moody 1998, Covington and Moore 1994a, Ganey and others 1996, Moir and Dieterich 1988, Moody and others 1992).

The Madrean Sky Island Archipelago, which includes parts of the Gila National Forest, consists of many isolated mountain groups. These mountains are important centers of biological diversity because of the convergence of northern and southern floral and faunal elements (Barton 1995, Felger and Wilson 1995, Warshall 1995). Organisms residing within these forests have evolved with fire as a natural process. Fires of the past were frequent and of low to moderate intensity. Recent fires have been catastrophic as a result of abnormal fuel build-up. These fires are likely to continue without meaningful fuels reduction. If they do continue, they could have far-reaching effects on the local

biota (Barton 1995, Caprio and Zwolinski 1995, Felger and Wilson 1995, Fule and Covington 1994, Ganey and others 1996, Grissino-Mayer and others 1995, Marshall 1957, Warshall 1995). Because stand replacement fires are thought to have been rare in the past, the recent increase of these types of fires is alarming. Localized extinction of isolated, unique populations of plants and animal species or even subspecies are a severe threat (Moir 1995).

Area Description

The Gila National Forest is comprised of 1,335,490 ha (3,300,000 acres), including 356,130 ha (880,000 acres) of wilderness. The Gila Wilderness has been managed as such since 1924 and is considered the first in the National Forest System. The Gila Wilderness was set aside 40 years before the passage of the Wilderness Act of 1964. Elevation ranges from 1,312 m to 3,323 m (4,300 to 10,895 feet) above sea level.

Vegetation types include spruce-fir and mixed conifer at high elevation along the Black Range and Mogollon Mountains with ponderosa pine the primary species near 2,135 m (7,000 feet). A mixed woodland of evergreen oak, pinyon pine, and juniper is found below 1,983 m (6,500 feet). The desert grassland subtends the woodland. Precipitation is derived from winter frontal systems and from summer thunderstorms generated by a monsoon flow from the tropics.

The Gila National Forest had one of the original prescribed natural fire plans within the National Forest System. This plan was implemented in 1975 and stated that the summer rains had to be well established before a lightning ignition could be managed as a natural fire. Returning fire to the forest under this early plan was treating very few acres. Since 1975, the Forest average was 452 ha (1,117 acres) while the average for the past 10 years has been 275 ha (681 acres).⁴ It was calculated that the Forest would have to burn approximately 40,470 ha (100,000 acres) each year to maintain a 10-year cycle in the ponderosa pine forest (Boucher and Moody [In press]).

Discussion and Conclusion

The perception of many who now live in the Southwest is that the current fire regime and vegetation had remained the same throughout the years, especially over the 100 past years. Photo documentation, in particular the use of historic photo retakes, proved to be most helpful in changing this perception. These photo pairs showed clearly that the number of trees on a given site, at the turn of the past century, was far lower than current conditions. They also gave evidence of heavy forage use by grazing ungulates. Many were unaware that vegetation types and conditions could change in such a short period of time. Although many refer to the change on the watersheds as "invasion" of one species or another, it is more realistically identified as a regeneration event brought on by livestock grazing, timber harvest outside of wilderness, and then fire suppression.

Threats from wildland fire grow each year as long-term effects from past land use and fire management actions become visible in natural vegetation communities. There are additional areas of consideration that fire managers have to deal with while making decisions as they relate to fire and these are clean air, clean water, cultural resources and endangered, threatened, and sensitive species. The 1990 Clean Air Act Amendments, New Mexico State Implementation Plan, and its memorandum of understanding with the Federal agencies maintains that smoke can become a problem after a fire reaches a certain size. During these situations, the New Mexico State Environment Division has requested that the forward spread of these fires be halted.

The Gila National Forest is unique in the Southwest Region of the USDA Forest Service in several ways. It has been using wildland fire with an approved plan since 1975. Before that, even with the attempts to implement the Forest

⁴ Unpublished data on file, Gila National Forest, New Mexico.

Service's "10 a.m. policy," fires within the two large wilderness areas frequently escaped initial attack. Reasons for these escapes included weather patterns, topography, and vegetation types that made early control difficult. The Forest is also isolated from major urban centers, and this has allowed more flexibility in dealing with the smoke problems that have plagued other forests. All of these factors have allowed the Forest to put fire back on most of its acres over the past 20 years. Some areas within the Gila Wilderness have even had multiple fires within the last 75 years.⁵

The economics of fire use have helped direct decisions back towards the natural cycle. The logistics of fighting fire within the Gila and Aldo Leopold Wildernesses make any attempt at full suppression a nightmare. Firefighter safety and the values at risk have generally led the decision process towards confining the fire within topographical features. This has limited the amount of disturbance within the wildernesses and has helped implement the minimum impact suppression tactics outlined in the Forest Wilderness Plan. Generally, fire-fighting personnel are far in front of the main fire, burning out trails and securing the perimeter. This tactic has provided for optimum firefighter safety. It has also limited the number of helicopter landing spots that have been needed as well as the number of safety areas that would have had to have been established for use in the event of an emergency.

Outside of wilderness, past silvicultural treatments have left areas in the ponderosa pine and mixed conifer vegetation zones capable of accepting wildland fire as well as prescribed fire, with minimal risk. The risks associated with burning during the dry periods of May and June are associated with basal and crown scorch. But historically, these risks have been a result of lightning ignited fires. Furthermore, the risks associated with the negative aspects of smoke are limited because of better ventilation and dispersion. The old school of thought that the value of the product would be lowered if the base were black is no longer valid. In reality, the value of timber after a stand replacement fire is far less than that of sawtimber and pulp that has been blackened at the base.

The Forest will continue to have the opportunity to use fire as a tool to reduce fuels and the risk and expense of large-scale wildfires. But fire, even on the Gila, isn't the right tool on every acre. In the future, the rising emphasis worldwide on carbon dioxide emissions and the possible implementation of international treaties may restrict prescribed fire. Restriction placed on the release of green house gasses like carbon dioxide could prevent the use of fire in some sections of the country. Even the restrictions in place with the current Clean Air Act have made it difficult to meet meaningful fuels reduction in some areas adjacent to urban centers. Some of these areas have not seen fire in more than 75 years and are ripe for disaster. Fuels reduction by mechanical means may be the only solution.

There is currently support for the use of fire to reduce fuels, but the removal of wood fiber by commercial means is not in vogue. Some people believe that cutting trees is wrong. That incinerating them through a stand replacement fire is

Table 1-Mean estimate "average" cost per acre and planning cost percentage for fuel treatment, in 1994 dollars, USDA Forest Service, Southwestern Region 3.

Region 3	\$/Acre	Pct. in planning
Slash reduction	76.25	13.7
Management ignited	37.81	20.2
Prescribed natural fires	6.75	62.5
Brush, range, and grassland	36.18	18.2
All types	39.25	16.5

⁵ Unpublished data on file, Gila National Forest, New Mexico.

acceptable. The cost of various mechanical treatments compared to natural fire is high. This could be offset if a product could be produced (*table 1*).

The urban interface issue and the potential for lawsuits that can result from a fire that escapes the perimeters of public lands during a burn and causes private property damage is a real threat. But this is minimal when one considers the potential loss of private property caused by a catastrophic fire in the future if nothing is done to alleviate the fuel problems that currently exist on those same public lands. What should be done?

We maintain that the public, State and local agencies and the Federal government are all in agreement to the need to accomplish meaningful fuels reduction. The major problems come as a result of the bad press when smoke remains in a community or city for several days; then, negative attitudes begin to develop. Also, do we truly understand how much it will cost and are we ready to repeat the treatment every few years? If natural cycles occur between 2 and 7 years, as with the Gila, one prescribed fire will not be enough. We will have to be committed to return to the same acres with additional dollars to continue the process.

We anticipate that the Gila and its fire reintroduction program will continue to prosper at least into the next decade. As fuels are reduced and the fire cycle approaches historical intervals, fire intensities and the problems with smoke should be lessened. But to accomplish this the Forest will have to burn about 41,000 hectares (100,000 acres) annually (Boucher and Moody [In press]). This is a high goal, and we doubt whether it can be maintained, considering the current political climate. It is too easy for a decision-maker to choose the full suppression alternative and avoid the potential for negative criticism that could come from problems with the use of wildland and prescribed fire. Strict accountability and critical postfire review of decisions should be implemented. This critique should help determine the correct course of action for future ignitions and aid in the decisions of how to best invest the public's money.

An incident with negative side effects can quickly cause either an agency administrator or fire manager to lose interest in the program. This is especially true when one considers that, currently, the public and politicians provide little criticism when a wildfire is declared, regardless of the cost. Suppression has been advocated, and a particular problem with a wildfire is not likely to jeopardize career aspirations. Unfortunately, the same cannot be said about agencies or individuals and their reputations if they are questioned because of political or public criticism dealing with a wildland or prescribed fire. If the agency is following their plans, then criticism is unfounded. However, if plans are not followed, criticism occurs.

The economic challenges are real. We should be less willing to pay for suppression and more willing to work with the natural process. The sale and removal of excess trees by mechanical means should be encouraged where appropriate. Ignitions that occur at a distance from urban centers need to be carefully evaluated before a full suppression alternative is implemented. After full suppression has occurred, a critical accounting through peer review should be conducted to help determine that dollars spent (cost plus loss) were wisely invested. This process should not become a witch-hunt but rather a method to better support decisions in the future.

The cost of doing nothing has already been well-documented. Are we willing to risk the health and well being of our natural resources? We hope not!

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Appropriate Management Responses to Wildland Fire: Options and Costs¹

G. Thomas Zimmerman²

Abstract

The Federal Wildland Fire Management Policy and Program Review, chartered and completed in 1995, represents the latest stage in the evolution of wildland fire management. The concept of appropriate management response is central to this policy. Through this approach, management responses are developed to reflect resource management needs and constraints, maximize a commitment to safety, be cost-effective, and accomplish desired objectives while maintaining the flexibility to vary intensity as conditions change. This concept accommodates use of the full range of responses. During the 1998 fire season in the Northern Rocky Mountains, appropriate management responses were developed consistent with the new policy and the full range of options. The appropriate management responses that were applied during August and September are discussed, with emphasis on descriptions of actions, ranges of costs, and contrasts among various responses. Specific examples of concurrent selected wildland fire use and suppression complexes are provided.

Throughout the 20th century, fire management policy and operational management have continued to develop in response to increasing land and resource management needs, expanding knowledge of the natural role of fire and suppression capability and effectiveness. During the early stages of wildland fire management, state-of-the-knowledge indicated that the preferred solution to limit widespread, damaging fires was aggressive, total suppression. As knowledge, understanding, and experience grew, it became increasingly obvious that complete fire exclusion was not the method to support a balanced resource management program. In fact, in many situations, this management direction was detrimental to ecosystem health and function.

Increasing awareness and concern among Federal land management agencies and constituents about safety, the impacts of wildland fire, and integration of fire and resource management resulted in a review of Federal wildland fire management policy. The Secretaries of the Interior and Agriculture convened a review to reaffirm and ensure that uniform Federal policies and cohesive and cooperative interagency and intergovernmental fire management programs existed. In response, the Federal Wildland Fire Management Policy and Program Review was chartered and completed in December 1995 (USDI /USDA 1995).

Under previous policy, Federal agencies' operational management options were limited by discrete classification of fire types. Operational efficiency was often compromised when fires were forced into specific categories. Frequently, managers were directed into responses because of policy guidelines and established rigid procedures rather than through consideration of resource management needs and desired objectives. Fiscal guidelines also drove management responses by limiting available funds for management options other than suppression. Economic efficiency was, in many instances, not fully evaluated during decision-making.

Challenges and risks pervasive to wildland fire management are increasing in both complexity and extent. Threats from wildland fires grow each year as long-term effects from past land use and fire management actions dominate

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natural vegetation communities. In addition, escalating values to be protected associated with current land use practices are compounding protection concerns and rapidly overextending Federal land management agencies' ability to respond to these challenges.

The future demands increased efforts to dramatically improve fire management program efficiency and accomplish resource management objectives. Wildland fire management policy and procedures must evolve to reflect new and critical considerations, capabilities, and direction, while being responsive to resource management objectives. Federal fire management agencies must change their expectations that all wildland fires can and should be controlled and suppressed. Absolute protection is an expectation that is difficult, if not impossible to achieve, and on the basis of workforce limitations, safety concerns, fiscal constraints, and environmental and fire behavior variables, is unrealistic. Operational implementation procedures must be developed that are commensurate with resource management objectives, safety, and cost efficiency. Incorporation of the best science, latest knowledge, and emerging technology will facilitate and support the highest quality and most effective fire management decisions and accomplishments.

Federal Wildland Fire Management Agencies are in the process of fully implementing the 1995 Federal Wildland Fire Management Policy. During the 1998 fire season, fire activity in the Northern Rocky Mountains provided a significant opportunity to put the new policy into practice. This paper clarifies the new Federal wildland fire management policy and appropriate management response concept; characterizes the range of appropriate management responses used during August and September, 1998 in the Northern Rocky Mountains, in terms of interrelationships among management objectives, land use, and operational actions; and presents wildland fire costs and contrasts them along the full spectrum of appropriate management responses.

Federal Wildland Fire Management Policy Discussion

The federal wildland fire management policy represents the latest stage in the evolution of wildland fire management and recommends policy changes that associate suppression and management of wildland fires into a single direction achieving multi-dimensional objectives. This policy directs Federal agencies to achieve a balance between suppression to protect life, property, and resources, and fire use to regulate fuels and maintain healthy ecosystems. Many of the previous limitations to expanded fire use are eliminated by this policy.

Differences between the previous and current Federal wildland fire management policy are typified by previous classification requirements that all fires were either wildfires or prescribed fires. This arbitrary classification of fires by types precluded maximum management effectiveness and strategic implementation. Under the new policy, all fires not ignited by managers for predetermined objectives are considered wildland fires. All wildland fires, then, have the same classification and receive management actions appropriate to conditions of the fire, fuels, weather, and topography to accomplish specific objectives for the area where the fire is burning. These management actions are termed the appropriate management response and will vary among individual fires. This type of management activity permits a dynamic range of tactical options that allows managers to continually operate at the most effective level. The new policy advocates greater application and use of fire for accomplishing resource benefits while maintaining and implementing an effective suppression program.

Key points made in the 1995 Policy Report (USDI/USDA 1995) include:

- Protection of human life is reaffirmed as the first priority in wildland fire management. Property and natural/ cultural resources are the second priority, with protection decisions based on values to be protected and other considerations.

- Wildland fire, as a critical natural process, must be reintroduced into the ecosystem. This will be accomplished across agency boundaries and will be based on the best available science.
- Agencies will create an organizational climate that supports employees who implement a properly planned program to reintroduce wildland fire.
- Where wildland fire cannot be safely introduced because of hazardous fuel build-ups, some form of pretreatment must be considered, particularly in wildland / urban interface areas.
- Every area with burnable vegetation will have an approved fire management plan.
- Both wildland fire management decisions and resource management decisions will be considered based on approved fire management and land and resource management plans. At the same time, agency administrators must have the ability to choose from the full spectrum of fire management actions --- from prompt suppression to allowing fire to function in its natural ecological role.
- All aspects of wildland fire management will be conducted with the involvement of all partners; programs, activities, and processes will be compatible.
- Agencies will develop and use compatible planning processes, funding mechanisms, training and qualification requirements, operational procedures, values-to-be-protected methodologies, and public education programs for all fire management activities.

Considerable confusion and misinformation has been associated with implementation of the new policy. New direction and opportunities represent marked departures from previous policy activities. To alleviate confusion and facilitate understanding and implementation, the intent of the policy can be graphically illustrated. A flowchart can represent an interagency-approved diagram, illustrating the broad framework of the new policy (*fig. 1*). This flowchart is an interagency-approved diagram forming the basis for policy description, illustration, and development of implementation procedures. The

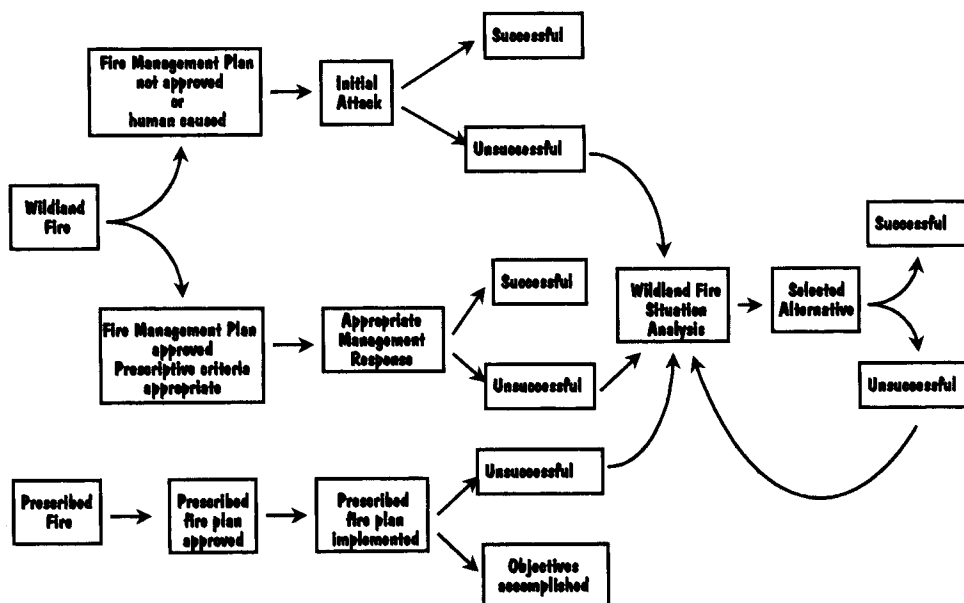


Figure 1

National Wildfire Coordinating Group (NWCG) Wildland Fire Management Policy flowchart (disseminated throughout the five Federal fire management agencies via internal agency communication directives).

flowchart depicts all ignitions as either wildland or prescribed fires. Wildland fire management can follow one of two pathways, depending upon completion of an administrative unit fire management plan.

Fire management plans, prepared by each administrative unit, or jointly by multiple units, are prerequisite to operational implementation. When a fire management plan is lacking, incomplete, or not approved, management options are substantially reduced. Without a plan, units may only implement initial attack suppression strategies. When a fire management plan has been completed and approved, and wildland fires are from natural ignition sources, the full extent of management options is available. These options range from monitoring with minimal on-the-ground actions to intense suppression actions on all or portions of the fire perimeter. The appropriate management response is developed from analysis of the local situation, safety, values-to-be-protected, management objectives, external concerns, fiscal concerns, and land use. Appropriate management responses resulting in aggressive suppression actions on unwanted fires correspond to old policy actions taken to suppress wildfires. Appropriate management responses resulting in management of wildland fires for resource benefits correspond to old policy actions of prescribed natural fire management. Under the new policy, opportunities to combine these strategies on individual fires are unlimited, implementing a variety of options concurrently is possible, and a distinction between fire types or strategic responses is eliminated.

The appropriate management response is the cornerstone of the new policy. Every wildland fire will receive an appropriate management response. Through its application, managers have the ability to maximize opportunities presented by every wildland fire situation. Appropriate management responses are neither replacements to prescribed natural fire nor alternatives to suppression. Managing fires for resource benefits and suppressing unwanted fires are basic strategic categories that are accomplished during implementation of one or more tactical options along the full spectrum of appropriate management responses. Appropriate management responses can be developed along a continuum from monitoring to aggressive suppression.

Range of Appropriate Management Responses Applied in 1998

During early August 1998, widespread lightning activity ignited over 200 wildland fires in the Northern Rocky Mountains. These fires were scattered throughout northern Idaho and western Montana on National Forest and National Park lands. Consistent with the new policy, appropriate management responses were applied to all fires. Assessments were made of underlying land management objectives, values-to-be-protected, primary land use, external influences, and other information pertinent to the fire location and situation. Conditions dictated that numerous fires receive an immediate management response to accomplish protection objectives through suppression. Other fires, actually a greater number than were suppressed, received management responses appropriate to realize opportunities to accomplish resource benefits, while maximizing firefighter safety by minimizing exposure, and remaining commensurate with cost effectiveness.

During this time, newly updated agency manuals had not been officially approved for the USDA Forest Service (USFS). As a result, it was not possible to fully implement the new policy in terminology, although fiscal allowances, management coding, and management responses were in place permitting consistency with new policy direction. The end result was that all wildland fires on National Forest lands managed for resource benefits during 1998 were described as prescribed natural fires to comply with agency manual direction in use at that time. Although this situation had little influence on the eventual outcome, it did foster limited confusion regarding terminology.

Table 1—Wildland fires managed for resource benefits by the USDA Forest Service and USDI National Park Service, 1994-1998.

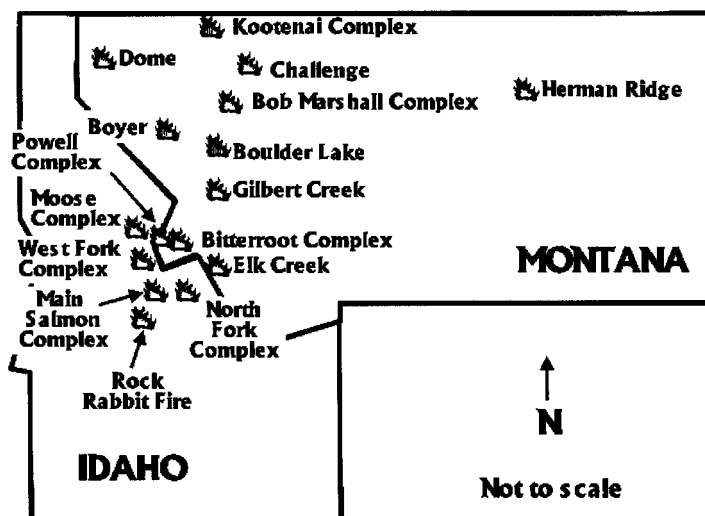
Agency	Numbers of wildland fire use actions by years ¹				
	1994	1995	1996	1997	1998
Forest Service (USFS)	26	91	164	70	113
National Park Service (NPS)	68	51	83	96	101
Total number of wildland fire use actions	94	142	247	166	214

¹Source: USFS and NPS file data, National Interagency Fire Center

A major difference separating the 1998 management effort from those of past years is related to the localized magnitude of fires managed for resource benefits. In previous years, fixed budgets severely limited the scale of prescribed natural fire accomplishments. Natural fire management budgets for both the USFS and USDI National Park Service (NPS) controlled the numbers of, and occasionally, the duration of prescribed natural fires. Once these budgets were exhausted or fully committed to potentially long-duration fires, all other new ignitions were forced into a wildfire designation and received an initial attack suppression response. If large resource commitments were not warranted, confinement responses were implemented.

During the past 5 years, the numbers of wildland fires managed for resource benefits shows a gradual increase, then slight drop off, reflecting seasonal severity and total numbers of ignitions (*table 1*). The total number of fires managed for resource benefits in 1998 was not the highest on record (*table 1*). But, instead of this total being comprised of fires occurring throughout the western United States, it was made up almost exclusively of fires concentrated in the Northern Rocky Mountains. More than 100 wildland fires were managed for resource benefits on the Flathead, Nez Perce, Payette, Salmon-Challis, and Bitterroot National Forests and Glacier National Park. The significance of managing this number of fires for this purpose becomes clear when understanding that during previous years, 75 percent of these fires would have been suppressed through aggressive initial attack or extended attack.

Because of the large numbers of fires in a few individual units, many fires in Idaho and Montana were aggregated into complexes to facilitate management (*fig. 2*). Those fires and complexes that represent the greatest range of appropriate management responses that will be discussed in this paper include: Rock Rabbit Fire, and Kootenai, Moose, West Fork, Main Salmon, Powell, Boyer, Dome, Challenge, Bob Marshall Complex, Boulder Lake, Gilbert Creek, Bitterroot Complex, Elk Creek, North Fork Complex, and Herman Ridge.

**Figure 2**

Wildland fire activity in Idaho and Montana from August to September 1998.

Individual fires ranged in size from less than one-quarter acre to more than several thousand acres. Appropriate management responses were designed for each fire or for groups of fires through preparation of Wildland Fire Implementation Plans (WFIP) when resource benefits were the dominant objective. When protection objectives and/or external influences indicated an overriding need for a suppression-oriented response, either an initial attack response was originated or a Wildland Fire Situation Analysis (WFSA) was used to formulate the preferred strategic alternative.

After reviewing the various appropriate management responses applied to fires managed individually or in these seven complexes, it was possible to consolidate the various appropriate management responses into tactical groups. These groups include monitoring from a distance, monitoring on-site, confinement, monitoring plus contingency actions, monitoring plus mitigation actions, initial attack, large fire suppression with multiple strategies, and control and extinguishment. These appropriate management response groups are defined as:

- Monitoring from a distance - fire situations where inactive behavior and low threats required only periodic monitoring from a nearby high point, lookout, or aircraft.
- Monitoring on-site - fires where circumstances required the physical placement of monitors on the fire site to track movement and growth.
- Confinement - actions taken when wildland fires were not viable candidates for resource benefits and an analysis of strategic alternatives indicated threats from the fire did not require costly deployment of large numbers of suppression resources for mitigation or suppression. These fires were managed with little or no on-the-ground activity and fire movement remained confined within a pre-determined area bounded by natural barriers or fuel changes.
- Monitoring plus contingency actions - monitoring was carried out on fires managed for resource benefits but circumstances necessitated preparation of contingency actions to satisfy external influences and ensure adequate preparation for possible undesirable developments.
- Monitoring plus mitigation actions - actions on fires managed for resource benefits that either posed real, but not necessarily immediate, threats or did not have a totally naturally defensible boundary. These fires were monitored, but operational actions were developed and implemented to delay, direct, or check fire spread, or to contain the fire to a defined area, and/or to ensure public safety (through signing, information, and trail and area closures).
- Initial attack - situations where an initial response was taken to suppress wildland fires, consistent with firefighter and public safety and values to be protected.
- Large fire suppression with multiple strategies - categorizes fires where a combination of tactics such as direct attack, indirect attack, and confinement by natural barriers were used to accomplish protection objectives as directed in a WFSA.
- Control and extinguishment - actions taken on fires when a WFSA alternative indicated a control strategy using direct attack was preferred. Sufficient resources were assigned to achieve control of the fire with minimum burned area.

The purpose of aggregating fires into these groups is not to create discrete types of appropriate management responses or a new classification of responses. It is strictly a single purpose effort of further exemplifying the dynamic, full range of appropriate management responses. These groups do not necessarily represent all possibilities and may not be applicable to all wildland fires. They do, however, provide a useful description of the range of appropriate management responses implemented during the wildland fire activity experienced from August to September 1998 in the Northern Rocky Mountains. Because of the high number of wildland fires managed during this period, it is difficult and repetitive to describe attributes of each individual appropriate management response. Describing groups of like responses is useful because it provides more concise, understandable information such as summaries of fire information, objectives, and management actions for each appropriate management response group, reduces redundancy, and offers a clear image of the fire situations and subsequent management activities (*table 2*).

As land use changes from wilderness to non-wilderness and multiple use direction, objectives for fire management also generally change (*table 2*). This strongly influences the dynamics of appropriate management responses. However, responses are not limited to one particular kind because of land use. For example, wildland fires in wilderness are not only subject to monitoring for resource benefits. One wildland fire in the wilderness area on the Powell Complex received a suppression response to achieve control. This was the appropriate management response based on the full array of considerations. In addition, within specific primary land uses, increasing threats drive appropriate management responses to include greater on-the-ground activity (*table 2*). Fire size and activity also demonstrate a major influence on the appropriate management response.

Numbers of fires can also be grouped by strategic response groups by complex to illustrate differences in appropriate management responses within each complex (*table 3*). Some complexes principally focused on implementation of various levels of monitoring actions while the attention of others was devoted to tactical implementation in support of critical protection objectives (*table 3*).

Costs of Appropriate Management Responses for Managing Wildland Fire

Under the previous fire policy, all wildland fires were considered as either wildfires or prescribed fires. Fires managed for resource benefits as prescribed natural fires were designated as part of the prescribed fire category. Because wildfires and prescribed natural fires were of different designation, cost comparisons between them logically developed. Under the new policy, all of these fires are considered wildland fires. Comparing costs among wildland fires does not lend itself to a meaningful analysis.

A review of costs for appropriate management responses can provide a useful contrast. This contrast demonstrates how dynamic appropriate management responses must be to respond to the range of fire situations and objectives. As appropriate management responses shift along the scale, management activity and costs will also react accordingly, but not necessarily linearly. Assuming managing fire for resource benefits and suppression to be strategic extremes of the appropriate management response spectrum, it can be expected that costs of both will vary considerably. Considerations associated with these strategic options such as the philosophy, objectives, and temporal considerations generate a considerable difference in management action focus, strategy, and tactics along the full range of appropriate management responses from one extreme to another (*table 4*). These factors all interact to cause widely variable costs.

Table 2-*Descriptions of fire situation and management actions for strategic groupings of wildland fires in the Northern Rocky Mountains, 1998.*

Strategic fire grouping	Fire situation and management action descriptors							
	Size	Fire activity	Threats	Primary objectives	Management organization needs	On-the-ground activity	Primary land use	Expected cost level
Monitoring from a distance	Small	Inactive	L ¹	Resource benefits	FUMT/Local ²	L ¹	Wilderness/ National Park	L ¹
Monitoring on -site	Small -- moderate	Inactive -- active	L -- M	Resource benefits	FUMT/Local	L	Wilderness/ National Park	L
Confinement	Small -- large	Inactive -- active	L	Protection	FUMT / Local	L	Wilderness/ National Park	L
Monitoring plus contingency actions	Small -- large	Inactive -- active	L -- M	Resource benefits	FUMT/ Local	L - M	Wilderness /National Park	L
Monitoring plus mitigation actions	Moderate -- large	Active	M -- H	Resource benefits	FUMT /Local	L - H	Wilderness/ National Park	L - M
Initial attack	Small	Inactive -- active	L -- H	Protection	FUMT /Local / IMT	L - M	Wilderness	M - H
Large fire suppression - multiple strategies	Moderate -- large	Active	M -- H	Protection	IMT / Local	M - H	Multiple use	H
Control - extinguishment	Large	Active	H	Protection	IMT/Local	H	Wilderness /Multiple use	H

¹ L = low, M = moderate, H = high² FUMT = Fire Use Management Team, IMT = Incident Management Team

Table 3—Summary of numbers of fires per appropriate management response grouping for wildland fire complexes, Northern Rocky Mountains, 1998.

Strategic fire grouping	Wildland fire complex							
	Rock Rabbit	Kootenai	Moose	West Fork	Main Salmon	Powell	North Fork	Bitterroot
Monitoring from a distance	1	1	4	9	8	3	--	--
Monitoring on-site	--	--	--	--	--	--	--	--
Confinement	--	--	--	4	6	2	--	--
Monitoring plus contingency actions	--	--	2	1	4	--	--	--
Monitoring plus mitigation actions	--	1	2	1	2	1	--	--
Initial attack	--	--	--	--	4	--	7	--
Large fire suppression - multiple strategies	--	--	--	--	--	--	1	--
Control - extinguishment	--	--	--	--	--	1	1	2

The goal of the new policy is not to force managers to select the least cost response but to let management and protection objectives guide selection of the most cost effective and efficient response to each wildland fire. The term "appropriate management response" does not and will not automatically translate to a wholesale decrease in wildland fire management costs in the future. Appropriate management responses to fires will reflect the correct action for a given situation. The likelihood exists that many future responses for a given situation will be different than for the same situation a few years ago (for example, the proportion of wildland fires managed for resource benefits in 1998 versus the proportion that would have received suppression responses a few years earlier). The likelihood also exists that for some specific situations, responses will never change. Costs of future management responses will show change, but these changes may present both lower and higher costs of fire management. Costs of responses to achieve different objectives will not show clear differentiation. Managing fires to achieve resource benefits will, for some fires, cost very little. In other cases, implementation of long duration wildland fire use actions on some fires could result in greater costs than if an immediate suppression had been implemented. A consideration necessary to evaluate immediate costs of wildland fire use is the fact that both short- and long-term effects of appropriate management responses are important. It is relatively easy to understand the short-term benefits realized from wildland fire use, but long-term gains are harder to comprehend and quantify. The value of restoration of fire as a natural process, reduction of hazard fuels, restoration of historic fire regimes and fuel complexes, effects on future wildland fire spread rates and intensities, and effects on future wildland fire suppression costs is hard to relate over a short time period. But these are major long-term goals worthy of substantial initial investments. The new policy established opportunities to realize a long-term return from managing fire for resource benefits that more than offsets any increased short-term costs.

Table 4-*Comparison of fire management considerations for wildland fire objectives of protection and resource benefits.*

Fire Management Consideration	Protection	Resource Benefits
Philosophy	Realize benefits from fire absence	Realize benefits from fire presence
Objectives	Protection objectives - suppression actions	Resource benefit objectives - fire use actions
Temporal considerations	Short-term focus	Long-term focus
Management action focus	Tactical operations, development of operational plans and identification of control line locations, short-term fire-growth projection, support Wildland Fire Situation Analysis decisions, suppression implementation actions.	Strategic planning, development of implementation plans and ultimate acceptable fire areas, long-range assessment, long-term fire-growth projection, support fire use decision-making, fire use implementation actions.
Strategy	Minimize loss	Maximize benefits
Tactics	Direct attack, necessary organization may become large	Monitoring plus required scale of combination of tactics to stop, direct, delay, or check fire spread; necessary organization remains small
Management Environment	Supportive, perception of low risk situation (high threat situation), outcome relatively certain, readily accepted.	Cautious, perception of high risk (low threat situation), outcome commonly uncertain or difficult to envision, associated uncertainty makes acceptance difficult.
Public Environment	Supportive, certain of purpose and actions.	Contentious, uncertain of purpose, actions, and outcome.

Substantial commitments of resources to control and extinguish fires and accomplish suppression objectives will result in the highest costs, often significantly higher than costs for most other management actions. Regardless of the final cost figures, fires managed through an appropriate management response received the best management direction, and costs were likely commensurate with considerations surrounding the fire situation and objectives to be accomplished.

Wildland fire costs are primarily comprised of personnel and equipment costs and support to tactical implementation. Generally, the proportional input to total costs ranks personnel highest, then equipment, and then support. As the appropriate management response moves along the gradient from monitoring to control and extinguishment, the required levels of personnel, equipment, support, on-the-ground activity, and management organization increase (*table 2*). This increased activity along the appropriate management response gradient generally, but not always, translates into increases in total costs.

Increasing numbers of fires managed by a single management organization and application of differential response strategies made it difficult to impossible to track costs on an individual fire basis. Neither cost tracking nor apportionment among fires were completed for each and every fire. Instead, costs were documented as totals for each complex. Total area burned, total costs, and cost

per acre information were determined for the seven wildland fire complexes in the Northern Rocky Mountains (*table 5*). The Rock Rabbit Fire figures represent a single fire and not a complex.

Managing fires for resource benefits does not always result in the lowest costs from a short-term perspective (*table 5*). When the correct appropriate management response was applied, that fire management action resulted in a defined set of costs (*table 5*). In some cases, the appropriate management response may have generated costs greater than expected. For given scenarios, costs of long-term monitoring plus additional management actions may begin to approach suppression costs.

Cost figures must be interpreted cautiously (*table 5*). How costs were accrued were not clear for figures representing aggregate costs for a complex. The costs per acre figures are merely an arithmetic output and do not offer a true picture of the cost for each acre managed in the complex.

The Main Salmon Complex can be used to illustrate limitations associated with a single cost/ acre figure for a complex. In the Main Salmon Complex, 24 fires were managed (*table 3*). Of these, eight were monitored from a distance with the only costs resulting from periodic aircraft overflights. Area burned by these fires was managed for relatively low costs. Conversely, the two fires managed with monitoring and mitigation actions necessitated placement of multiple crew resources (20 - 50 personnel at varying periods) to install structure protection equipment, set up and test a water delivery system, plan and complete a boundary strengthening burnout operation, monitor daily fire spread, behavior, and weather, patrol boundary areas, and enforce area closures to maintain maximum public safety. These fires accumulated costs from daily aircraft overflight and mapping, and equipment, supply, and personnel delivery, as well as necessary support. The implication to the complex cost figure is that these two fires could have accounted for as much as 50 percent of the Main Salmon Complex costs, while a greater number of fires in the complex, with more acres burned, could have accounted for a lower proportion of costs and a markedly lower cost per acre figure. Further inflation of costs for the complex occurred from interregional and interstate coordination activities with Idaho and Montana State Departments of Environmental Quality to monitor and model smoke production and dispersal. Although efforts were concentrated in the Salmon area, they monitored and affected all fires and complexes. However, all activity costs were included in the Main Salmon Complex figures, rather than amortized over all fires.

Thus, for this as well as all complexes, it can be confirmed that while the total cost figure is an accurate representation of the expenditures necessary to accomplish objectives for all fires in the complexes, the cost per acre figures do not completely portray the costs of managing each individual fire. The Rock

Table 5--Summary of area burned and costs for wildland fire complexes, Northern Rocky Mountains, 1998.

Wildland Fire Complex	Area burned (acres)	Total cost (\$)	Cost per acre (\$)
Rock Rabbit	7,198	23,566	3
Kootenai	9,500	650,000	74
Moose	1,654	378,000	228
West Fork	8,937	470,000	54
Main Salmon	21,650	1,137,000	52
Powell	5,223	229,300	44
North Fork	7,223	5,206,000	721
Bitterroot	4,090	2,098,000	513

Rabbit Fire does provide an indication of tracked costs for an individual fire and is certainly representative of the area along the appropriate management response spectrum generating the lowest costs.

Within the seven complexes, it can be assumed that cost of managing each fire increased as the on-the-ground activity levels increased. Implementation of mitigation actions requires tactical deployment of personnel and their support. Costs for this type of activity will exceed those for situations where monitoring is the single tactical operation.

At the other end of the appropriate management response spectrum, the North Fork and Bitterroot Complexes consisted of fires only receiving suppression-oriented appropriate management responses (*table 2*). These fires posed greater threats, were located in areas where fire presence was undesirable, and necessitated large resource commitments and on-the-ground activity. Consequently, costs appear very high, but given the location, situation, and objectives, the costs reflect the expense of implementing the necessary appropriate management response. It can be assumed that any other response would not have achieved the objectives as well or as cost-efficiently. The personnel and equipment needs necessary to accomplish objectives in these complexes are much higher than for any other appropriate management response shown. This is the single most important factor contributing to elevated costs for these complexes.

Further interpretation of the differences in appropriate management response costs can be gained by reviewing costs per day for the various fires and complexes. Fire management considerations show great variation for different aspects of the appropriate management response spectrum (*table 4*). Specifically, temporal considerations are dramatically different. Implications of this difference are illustrated by the Main Salmon and North Fork Complexes. On the Main Salmon Complex, fires were managed by a formal management organization for 39 days while fires in the North Fork Complex were managed by a formal management organization for 26 days. Costs to accomplish the Main Salmon Complex objectives averaged about \$26,600 per day and the North Fork Complex costs averaged nearly \$200,200 per day. After transition from the management teams to the local unit, the Main Salmon Complex fires continued to burn until extinguished by weather. The North Fork Complex fires were extinguished along their perimeters but experienced some interior burning until extinguished by weather.

This huge disparity in daily costs reflects the magnitude of the on-the-ground activity, the scale of resources needed to accomplish the objectives, and the seriousness of the threats from the fires. In each case, the management response was appropriate to the situation and accomplished desired objectives. At the other end of the scale, the Rock Rabbit Fire was managed throughout its entirety by local unit forces. Costs of this fire reflect a lower, but constant, level of attention and scrutiny for over 50 days, which equates to about \$470 per day.

Conclusions

As Federal agencies fully implement the 1995 Federal Wildland Fire Management Policy, implementation opportunities and varied accomplishments will broaden. The concept of applying an appropriate management response to every fire rather than standardizing responses by designated fire types will promote greater efficiency. Reflected in this enhanced efficiency will be greater attention to ecological concerns, greater responsiveness to resource management objectives, greater ability to accommodate evolving objectives, more effective assignment and use of limited resources, and the most efficient expenditure of funds.

Evaluating costs of implementing appropriate management responses has mixed relevancy. Comparing costs incurred under the new policy procedures with those generated during implementation of procedures under the old policy

does not provide a valid or useful comparison. The costs per acre of managing fires with different strategies within a single complex, or of managing a single large fire with several different strategies concurrently, cannot be directly compared with the cost/acre under previous response strategies.

Contrasting costs along the full range of the appropriate management response spectrum will provide a more meaningful evaluation. Because of the disparity in requirements for accomplishing differing objectives, comparisons of specific objectives, strategies, and costs within wildland fire management are also limited in value. There will not be a well-defined break between various fire management strategies; similar tactics of different scales will be applied to accomplish different objectives. As a result, costs of wildland fire management will vary considerably and managing fires for resource benefits will generally be lower than costs of suppressing fires for protection objectives. However, numerous situations will occur in which suppression costs will be lower than those for fire use applications.

As the new policy becomes fully implemented and agencies' expertise and experience in implementing appropriate management responses grows, baseline data will be established for future evaluations of program efficiency and effectiveness. The 1998 fire season in the Northern Rocky Mountains provided a thorough test of the new policy. During this period of activity, the soundness of appropriate management response was demonstrated while the dynamic nature presented by the range of tactical options available, the variety in implementation actions utilized, and the range of variability of costs within groups of similar appropriate management responses were obvious. Costs of implementing appropriate management responses in the future may not result in wholesale reductions in expenditures, but should show reductions in some areas. Whether the costs increase or decrease, at least they will exhibit a more logical relationship to resource benefits and values protected than was evident under previous suppression-oriented strategies. The 1998 fire season activity will provide a foundation for future evaluation and continued improvements to the wildland fire management program and will facilitate accomplishment of the complete array of management objectives.

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Postfire Hillslope Erosion in Southern California Chaparral: A Case Study of Prescribed Fire as a Sediment Management Tool¹

Peter M. Wohlgemuth,² Jan L. Beyers,² Susan G. Conard³

Abstract

Land managers in southern California have speculated that prescribed burning could reduce the soil erosion generated by catastrophic wildfires. A unique opportunity to test this notion arose when a wildfire swept over an ongoing field experiment measuring hillslope erosion from a prior prescribed burn. Results indicate that fire severity can affect erosion response, that postfire hillslope erosion levels can return to normal within 3 years, and that prescribed fire can reduce the erosion produced by future wildfires. On the basis of these results, an economic analysis for a hypothetical watershed suggests that prescribed fire can be a viable sediment management tool.

Introduction

Chaparral is the thick blanket of fire-prone brush that covers the lower and middle elevation foothills throughout much of California. This evergreen shrub-dominated plant community with a sparse herbaceous understory covers about 11 percent of the State (Barbour and Major 1988). Chaparral ecosystems appear to be adapted to both summer droughts, associated with the strongly seasonal Mediterranean-type climate, and periodic burning (Axelrod 1989, Zedler and Zammit 1989). Indeed, fire may be necessary for ecosystem perpetuation, as it stimulates the regeneration of many chaparral shrub species (Barro and Conard 1991).

Chaparral typically burns in stand-replacing crown fires that exhibit spectacular fire behavior and have a return interval of 20 to 100 years (Conard and Weise 1998). In heavily populated southern California, where human development has encroached on chaparral brushfields at the urban/wildland interface, fire in chaparral threatens nearby residential communities. Moreover, catastrophic wildfires alter the surface soil conditions, rendering the postburn landscape susceptible to massive erosion, flooding, and downstream sedimentation with the onset of heavy winter rainstorms (Rice 1974, Wells 1981). Consequently, the economic impacts of wildfire and accelerated erosion in chaparral are tremendous.

One method to mitigate the impacts of catastrophic wildfires is through a program of prescribed burning. Selectively burning strategic corridors and buffer zones can reduce hazardous fuel conditions adjacent to urban areas (Green 1981). Prescribed burning of larger land units can also create a mosaic of vegetation age classes on the landscape that will reduce the fire severity in the event of a destructive wildfire and aid suppression efforts in effective fire control (Conard and Weise 1998, Riggan and others 1994). Thus, both the amount of damage and the cost of suppression could be reduced by using prescribed fire as a vegetation management tool.

It has further been suggested that prescribed fire could be used as a sediment management tool. Burning a smaller area under more moderate conditions that generates less site disturbance than a wildfire should reduce the loss of soil and

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nutrients (Green 1981). Because the potential for extensive damage and expensive cleanup costs associated with accelerated erosion in fire-prone chaparral ecosystems is enormous, any reduction in the volume of generated debris would result in cost savings.

Unfortunately, the utility of prescribed fire as a sediment management tool in chaparral has not been adequately demonstrated in the field. Pase and Lindenmuth (1971) reported that a prescribed fire generated only 10 percent of the sediment produced by a wildfire in a comparable area in central Arizona. In southern California, watersheds burned under a moderate intensity prescription yielded only 35 percent as much water and sediment as watersheds burned under a high intensity prescription intended to simulate a wildfire (Riggan and others 1994). Although both these studies suggest that the erosion response after a prescribed fire is lower than that after a natural burn, neither was able to address the impact of prescribed burning on future wildfires.

A long-standing controversy in the management of chaparral ecosystems involves the seeding of introduced grass species as a postfire emergency rehabilitation measure for erosion control (Barro and Conard 1987). Managers are under conflicting pressures to seed burned hillslopes to protect life and property and not to seed to protect native plant communities and endangered species. Much of the controversy has stemmed from the lack of objective data, derived from rigorous field-testing, that managers need to make informed decisions.

To address the question of grass seeding as a viable postfire rehabilitation technique, the USDA Forest Service, in partnership with the California Department of Forestry and Fire Protection, initiated burning and seeding field experiments in 1988. The purpose of this project was to investigate postfire hillslope erosion and vegetation development, and the effect of annual ryegrass for emergency watershed protection, on chaparral sites (Beyers and others 1998b, Wohlgemuth and other 1998). This paper discusses the result of our study on postfire erosion at one of the field sites in southern California that may illuminate the use of prescribed burning as a sediment management tool.

Study Area

The Belmar study area is located in the Peña Canyon watershed on the southern slopes of the Santa Monica Mountains, above the costal community of Malibu, California (fig. 1). Although the Belmar area constitutes an unreplicated case study, it represents much of the central and western Transverse Ranges of southern California in geology, soils, climate, and vegetation, where the problems of fire and accelerated postfire erosion are particularly acute. The characteristics of the Belmar study area are:

Distance from the coast	2 km
Elevation	450 m
Mean aspect	south
Mean slope angle	27°
Parent rock type	sedimentary, primarily sandstone
Soil series	Millsholm
Soil texture	sandy loam
Mean annual precipitation	467 mm

The Belmar site was established in January 1988 and was burned the next June by the Los Angeles County Fire Department. This prescribed fire burned with moderate fire severity-based on the depth of soil char, the diameter of the remaining plant stems, and the degree of consumption of ground litter and foliage (Wohlgemuth and others 1998). However, because of a sharp rise in relative humidity during the prescribed fire operation, it only burned about half

California

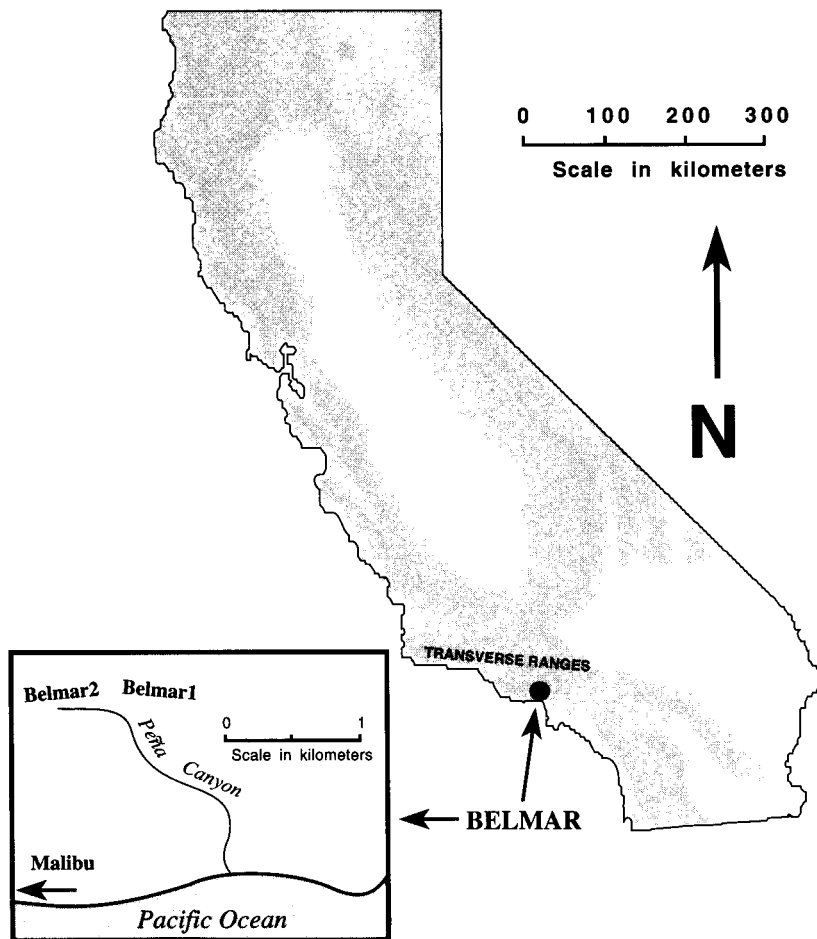


Figure 1

Study area in the coastal southern California mountains.

the site. The unburned portion was eventually abandoned, but the erosion measurement equipment was never removed. The entire Peña Canyon watershed was subsequently burned in the wind-driven Old Topanga Fire of November 1993. The wildfire burned under more severe weather conditions than did the original prescribed burn. Consequently, the prescribed burn section of the Belmar site re-burned with moderate to high fire severity, while the previously unburned vegetation was completely consumed with very high fire severity (Wohlgemuth and others 1998).

Methods

We initially established 70 erosion plots over a 60 ha (150 ac) area in mature mixed chaparral at the Belmar site. Each erosion plot consisted of a segmented sheet metal sediment collector trap with a 1.5 m aperture parallel to the slope contour and an approach apron flush with the mineral soil surface (Wells and Wohlgemuth 1987). These unbordered erosion plots were situated at midslope positions, with the potential contributing area extending to the hillslope crest. Ten of the plots were established outside the firelines to serve as unburned controls. After the prescribed fire, partially burned and unburned erosion plots within the firelines were discarded, and the remaining plots comprise the Belmar1 site (*fig. 1*). After the wildfire, many of the abandoned erosion plots and the previously unburned controls were reactivated as burn plots, constituting the Belmar2 site (*fig. 1*). After both fires, some new erosion plots were established to increase the sample size to 39 and 36 for the Belmar1 and Belmar2 sites, respectively.

Sediment was gathered periodically from the collector traps and taken to the laboratory, where it was dried and weighed. The preburn erosion record consisted of a single collection from January to June 1988, comprised predominantly of wet season sediment movement. Postfire erosion was measured with decreasing frequency for 5 years after each fire. The erosion data were aggregated into wet season (roughly November to March) and dry season (April to October) collection periods, based on the precipitation patterns from a local rain gauge (Wohlgemuth and others 1998).

Most of the erosion plots that became the Belmar2 site were abandoned after the 1988 prescribed burn, and measurements at the Belmar1 site were terminated after 5 years of postburn monitoring in the spring of 1993. Thus, gaps exist in the erosion record of both sites before they were reactivated after the fall 1993 wildfire. Although the magnitudes of the missing data points were small, to compare the erosion response for both Belmar sites over the entire 10-year life of the project, we relied on estimation procedures to fill in these gaps. The missing erosion values for the unburned Belmar2 site were estimated from the relationship between the prefire erosion measurements and those from the unburned controls. The missing values for both sites for the dry season 1993 were estimated by multiplying the median 1992 dry season erosion rate (amount divided by duration) by the duration of the 1993 season.

Because of unequal sample sizes, non-normally distributed data, and our desire to avoid numerical transformations in analyzing the data, central tendency and dispersion were characterized as the medians and semi-interquartile ranges of the distributions. Subsequent statistical analysis used the non-parametric Wilcoxon rank sum statistic (Dixon and Massey 1969) to compare the postfire erosion responses of the various fire scenarios.

Results and Discussion

Wildfires at the wildland /urban interface are seldom beneficial. At the mouth of Pena Canyon during hydrologic year 1994, minor property damage occurred associated with accelerated postfire flooding and erosion (Franklin, pers. comm.). However, the serendipity of an incomplete prescribed burn followed by a wildfire over a site instrumented to measure hillslope erosion afforded us a unique opportunity to evaluate the utility of prescribed fire as a sediment management tool. Specifically, we were able to quantify the postfire erosion response from three distinct fire cases for essentially identical site characteristics: a moderate severity prescribed burn, a moderate to high severity short-interval re-burn, and a very high severity wildfire.

General Post fire Erosion Response

The magnitude and duration of the postfire erosion response of the prescribed burn and the re-burn appear similar (*table 1*), despite the differences in fire severity. Results of the statistical analyses confirm that the two cases were comparable in the immediate postburn environment (the first two years postfire), but show that the prescribed burn produced significantly more ($p=0.03$) erosion over the 5-year study period than did the re-burn. In contrast, the erosion response of the wildfire was 10 times greater than the other two cases during the first two postfire wet seasons (*table 1*) and was significantly greater ($p<0.01$) than the prescribed fire or the re-burn over the 5-year study period. This is consistent with previous observations (Pase and Lindenmuth 1971) and reflects the greater degree of site alteration (foliage and litter consumption, surface soil structure disruption, degree of soil non-wettability) associated with very high severity fires. Because of the initial postfire erosion spike after the wildfire, the abrupt return to normal erosion levels may seem to be quite remarkable. However, our research has shown that burned hillslopes are very resilient, typically recovering to prefire erosion rates in 2 to 4 years (Wohlgemuth and others 1998).

Table 1—Postfire erosion by season and year postfire at the Belmar study area.

Year postfire		Belmar bum sites		
		Prescribed burn	Re-burn	Wildfire
		-----Kilograms-----		
Year 1	Dry season	¹ 0.35 ± 0.46	(²)	(²)
	Wet season	6.99 ± 2.84	5.40+7.70	97.62 ± 38.55
Year 2	Dry season	3.91 ± 2.82	0.67 ± 0.74	0.70 ± 0.72
	Wet season	2.02 ± 2.25	0.63 ± 0.47	23.34 ± 27.70
Year 3	Dry season	1.69 ± 5.48	1.04 ± 1.34	1.13 ± 0.74
	Wet season	0.51 ± 0.56	0.39 ± 0.71	0.21+0.19
Year 4	Dry season	1.76 ± 4.70	0.50 ± 0.80	0.33 ± 0.55
	Wet season	0.64 ± 0.92	0.22 ± 0.12	0.26 ± 0.11
Year 5	Dry season	0.46 ± 0.57	0.17 ± 0.27	0.15 ± 0.48
	Wet season	0.36 ± 0.46	0.25 ± 0.21	0.24+0.50

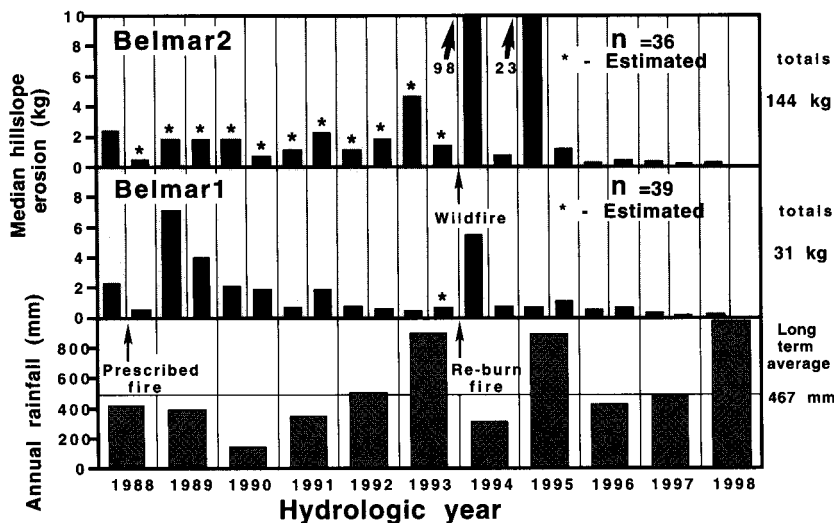
¹Median and semi-interquartile range.²As the rainy season commenced shortly after the wildfire, there was no appreciable Year 1 postfire dry season.

Controlling Factors

Factors governing postfire erosion response in southern California are precipitation, vegetation regrowth, and perhaps the depletion of hillslope sediment supply. Generally, postfire soil erosion is more pronounced in wet years than during sub-normal rainfall years, while a greater cover of herbaceous vegetation regrowth has a better ability to retard soil movement (Beyers and others 1998a, Wohlgemuth and others [In press]). We have also speculated (Wohlgemuth and others 1998) that most of the supply of loose, easily erodible soil may be removed in an initial postfire flush, exposing more compacted soil material at the surface during subsequent years.

In addition to the moderate fire severity, the modest erosion response after the Belmar1 prescribed burn was probably a result of the prevailing drought conditions (*fig. 2*) that may have also depressed vegetation regrowth. Erosion levels remained low relative to the estimated erosion for the unburned Belmar2 site with the return of wetter weather in 1992-93 (*fig. 2*). These levels may be the result of differences in vegetation (thick herbaceous ground cover on Belmar1 versus chaparral with a negligible understory on Belmar2) but may also reflect hillslope sediment depletion.

The Belmar1 re-burn and the Belmar2 wildfire sites burned simultaneously and experienced identical postfire weather patterns: a low rainfall year, followed by a very wet year, followed by 2 years of nearly normal precipitation (*fig. 2*). The

**Figure 2**

Hillslope erosion and annual rainfall at the Belmar sites by hydrologic year (October 1 to September 30). The shaded background columns are wet season erosion; the unshaded columns are dry season erosion. Column widths are standardized and do not represent the actual season durations.

re-burn site produced only moderate erosion initially and very minor erosion during the subsequent years. This probably reflects the patterns of vegetation regrowth, as the herbaceous cover was two to three times greater after the Belmar1 re-burn than after either the Belmar1 prescribed fire or the Belmar2 wildfire (Beyers and others 1998a). Presumably, the seed bank from the herbaceous plant community after the prescribed fire at the Belmar1 site sprouted vigorously after the re-burn, and the additional cover afforded greater site protection against postfire erosion, even in a very wet year. This would explain the results of our statistical analyses and the lower levels of erosion after the Belmar1 re-burn than after the prescribed burn. Alternatively, the lower level of erosion in the higher rainfall years after the short-interval re-burn may reflect a depletion of hillslope sediment supply.

In contrast, after the wildfire, the Belmar2 site generated substantial sediment movement for both the low and high rainfall years, then abruptly ceased (*fig. 2*). The amount of herbaceous cover after the wildfire was nearly identical to the amount after the Belmar1 prescribed burn (Beyers and others 1998a) in a low rainfall year. This finding strongly suggests fire intensity is a major factor in governing the magnitude of postfire erosion. Despite the relatively rapid recovery period, soil erosion from the wildfire was greater than from the other two fire cases combined. Over a 10-year period for identical site characteristics and rainfall patterns, the Belmar1 prescribed fire and short-interval re-burn together produced only 22 percent of the soil erosion from the Belmar2 wildfire and estimated preburn record (*fig. 2*).

Economic Analysis

By using the postfire erosion response relationships from the Belmar study area, an economic analysis can be developed for a hypothetical southern California watershed comparing the cost of sediment management resulting from prescribed burning to that from wildfire. We assumed a hypothetical intermediate-sized watershed of 400 ha (1,000 ac). From map analysis, we calculated a drainage density (total length of stream channels per unit area) of about 9 km / km² for comparably-sized watersheds in southern California.⁴ This yields a total length of channels of 36 km or 36,000 m for our 4 km² hypothetical watershed and a total hillslope /channel interface of 72,000 m (as a channel has two banks). Wohlgemuth (1996) reported that the amount of sediment moving down a southern California hillside is comparable to that delivered from the hillslope to the channel. Thus, the total amount of sediment reaching the channel is the product of the interface length times the erosion level.

For the 10-year period at the Belmar1 site that included the prescribed fire and the re-burn, the cumulative median erosion was 31 kg per 1.5 m of slope contour (*fig. 2*). For our hypothetical watershed, this yields 1.488 million kg of sediment. By using the standard density of 1.0 g CM⁻³ for loose, unconsolidated sediment, this produces 1488 m³ of eroded material. If a conservative channel delivery coefficient of 0.5 is used to route the sediment down the stream network, this means that 744 m³ of material would be delivered to the watershed mouth—for example, a debris basin protecting some downstream residential community or a water supply reservoir. Finally, if it costs about \$15 M⁻³ to clean out a debris basin (Bolander, pers. comm.), the total cost of sediment management under this scenario would be about \$11,000.

For the 10-year period at the Belmar2 site that included the wildfire, the cumulative mean erosion was 144 kg per 1.5 m of slope contour (*fig. 2*). By using the same procedures, our hypothetical watershed would deliver 3,456 m³ of sediment to the debris basin, generating a total cleanup cost of about \$52,000. Thus, over a 10-year period, prescribed fire could save \$41,000 on the cost of sediment management. If the cost of prescribed burning is about \$250 ha⁻¹ (Faser, pers. comm.), then the savings in sediment management would be about 40

⁴Unpublished data on file, Pacific Southwest Research Station, Riverside, Calif.

percent of the cost of burning the hypothetical watershed. Admittedly, the savings in sediment management resulting from prescribed burning is small compared to the estimated savings of \$2,500 ha⁻¹ in suppression costs in the event of a wildfire (Faser, pers. comm.). However, the savings in sediment management is itself a considerable sum that needs to be included in any cost-benefit analysis, and suggests that prescribed fire is an economically viable sediment management tool.

Conclusions

Fire and accelerated postfire erosion in southern California chaparral are inevitable. It has long been suggested that prescribed fire could be used as a sediment management tool to mitigate the potentially disastrous erosion effects of catastrophic wildfires, but little objective data have been available to confirm this notion. After a fortuitous wildfire burned over the area of a former prescribed burn and a previously unburned companion site, we were able to compare the erosion response of three fire scenarios for essentially identical site characteristics. Data from the Belmar area indicate that fire severity affected erosion response, as the wildfire case generated 10 times as much sediment as the prescribed burn in the first postfire winter with similar amounts of rainfall and vegetation regrowth. Postfire erosion recovered to normal levels in as little as 2 years, although it is unclear to what degree these measured responses reflect vegetation regrowth or the depletion of the supply of loose surface soil. Prescribed fire reduced the hillslope erosion of a future wildfire in the Belmar area, with the prescribed fire plus the re-burn cases together producing only 22 percent of the sediment generated by the wildfire. By using the erosion responses from the Belmar area, an economic analysis for a hypothetical watershed indicated that prescribed burning can result in considerable savings in sediment management costs in the event of a wildfire. Undoubtedly, the specific erosion and cost values would be different at other study sites with different fire characteristics and rainfall patterns, but it is likely that the general trends would be similar. Although more examples are needed to fully explain the effects of prescribed burning on the erosion response of future wildfires, this case study suggests that prescribed fire can be an effective and economically viable sediment management tool.

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Prescribed Burning Costs: Trends and Influences in the National Forest System¹

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Abstract

The results of a survey from 1985 to 1994 of the USDA Forest Service's National Forest System prescribed burning activity and costs are examined. Fuels management officers from 95 National Forests reported costs and acreage burned for 4 types of prescribed fire, including slash reduction, management-ignited fires, prescribed natural fires, and brush, grass, and rangeland burns, and rated the relative importance of 9 resource enhancement targets and 12 factors influencing burning costs. Substantial differences were found in per acre costs and cost variability by burn type, National Forest Regions, and resource target mix. Planning costs were estimated to be about 25 percent of total costs in most regions. Unit size, labor availability, escape fire safeguards, and environmental restrictions were the most important cost influences, but these varied by region. Data limitations suggest the need for a uniform, comprehensive system of data collection on prescribed burning activity and costs.

Recent analyses of fire policy have called for increased prescribed burning to enhance fire-dependent ecosystems and commercial forests and to prevent future wildfire damage (Bell and others 1995, Mutch 1994, USDA Forest Service 1994, USDI 1995). The USDA Forest Service has set a goal of burning 3 million acres per year by the year 2005 (Bell and others 1995). Achieving this goal requires an understanding of the costs of burning options. The costs and the risks imposed by burning options must be balanced against their ecological and risk reduction benefits.

This paper summarizes findings on costs and cost influences extracted from a survey conducted to characterize and quantify prescribed burning activity in the Forest Service's National Forest System from 1985 through 1994 (Cleaves and others [In press]). This survey was a comprehensive assessment of prescribed burning activity levels, resource target mixes, barriers to increased use of burning, costs, and cost influences. It attempted to interpret the physical, social, legal, economic, and managerial factors that shape the burning programs on National Forests. A brief summary of the activity and resource target mix results is provided to help explain cost differences among regions and burning types.

Methods

Analyses were based on responses to a questionnaire mailed to National Forest district and forest-level fuels management officers (FMO's) in December 1995. The questionnaire asked for estimates for the following variables for the period 1985-1994: annual acres burned, number of burns and cost for four burn types--slash reduction, management-ignited burns in natural fuels, prescribed natural fires, and brush and range burns; major resource benefits targeted in the burning program; and historic trends and future expectations in burned acreage by type of burn. Fuels managers ranked the importance of the selected resource targets and cost influences on a scale of 0 to 5 with 5 being most important.

We received completed surveys from 95 of the 114 National Forests contacted, which represented about 85 percent of the National Forest acreage, excluding Alaska. We aggregated forest-level estimates into regional totals and averages and compared burn sizes, costs, trends, and other parameters across National Forest Regions.

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The respondents provided average, highest, and lowest cost estimates, and apportioned those costs into planning and project categories. Project costs included: preparing the burn site, ignition and maintenance, mop up, post-fire monitoring, contractor or cooperator costs, and other related activities. Planning costs included burn plan preparation; National Environmental Policy Act (NEPA) compliance and public involvement, project planning, and appeals; post-fire evaluation of effects; smoke management; interdisciplinary teamwork; and general overhead. Cost estimates were summarized and compared across burn types, Regions, and other parameters.

To confirm overall trends and evaluate data quality, we compared our estimates with data from Forest Service obligations records for fiscal years 1980 through 1995 (Bell and others 1995, Cleaves and others 1997, Schuster and others 1997). In those reports, per-acre expenditures were calculated for each Region from the obligations data. This data provided detailed funding information about fuels treated with appropriated fuels funds (FFFP), brush disposal (BDBD), Knutson Vandenberg (CWKV), and contributed or volunteer (cooperative) work (CWCW). Prescribed burning funded by benefiting Forest Service programs, such as wildlife, timber management, threatened and endangered species, recreation, range, and others, is often recorded under more general activity codes.

Results

Background Findings

Activity Levels

The total annual prescribed burned area in the responding National Forests averaged 908,120 acres. The Southern Region (Region 8) reported the highest annual average burned area at 434,119 acres. The Southwestern Region (Region 3; 184,248 acres) was next highest, followed by the Pacific Northwest (Region 6; 114,674 acres), Northern (Region 1; 77,186 acres), Pacific Southwest (Region 5; 54,401 acres), Eastern (Region 9; 16,213 acres), Intermountain (Region 4; 15,412 acres), and Rocky Mountain (Region 2; 11,867 acres).

Management-ignited prescribed fires accounted for the largest acreage burned, totaling 62.2 percent of the system total. This was followed by slash reduction (25.3 percent), brush and rangeland (8.3 percent), and prescribed natural fire (4.2 percent). Most of the management-ignited acreage (87.6 percent) was reported in the Southern and Southwestern Regions. Most of the slash burning acreage (70.7 percent) was reported in the Pacific Northwest, Southwestern, and Northern Regions. The majority of brush and rangeland burning (62.7 percent) was conducted in the Southwestern and Pacific Southwest Regions.

Overall, the responding forests conducted an average of 6,763 burns per year in which 75 percent were slash reduction burns and 20 percent management-ignited burns in natural fuels. Accordingly, Regions with significant slash burning acreages reported the highest number of burns. The Pacific Northwest Region was the highest at 1,816 burns per year, followed by the Northern Region (1,727), the Pacific Southwest (1,281), and Southern Region (947).

The average burn size was 134 acres. This varied from 42 acres in the Pacific Southwest Region to 458 acres in the Southern Region. The Southern and Southwestern Regions conducted the largest burns with average sizes of 458 and 441 acres, respectively. All the other Regions averaged less than 90 acres.

The largest burns were for prescribed natural fires (620 acres); the smallest for slash burns (45 acres). Management-ignited burns were the second largest (411 acres) followed by brush and range burns (306 acres). This relationship of relative sizes of burn types was similar for most Regions.

Respondents reported whether annual burning activity had increased, decreased, or remained constant over the period 1985-1994. The slash burn acreage had decreased in more forests (60 percent) than any other burn type

because of reductions in timber harvests. Management-ignited burning had increased in 76 percent of the responding forests, because of increasing fuel treatment budgets and greater emphasis on the use of prescribed fire for silviculture, ecosystem, and wildlife purposes. Prescribed natural fire levels had remained fairly constant except for a large increase in the Southwestern Region. Brush and rangeland burns had either remained stable or increased, particularly in the Southwestern and Intermountain Regions.

Resource Target Mixes

Respondents rated the relative importance of nine resource targets for prescribed burning on a scale of 0 to 5. The highest rated resource target was hazard reduction (4.21), followed by ecosystem fire reintroduction (3.65), game habitat (3.15), reforestation (2.85), nongame habitat (2.37), vegetation control (2.26), threatened and endangered species (2.15), insect and disease protection (1.71), and grazing (1.70).

Mixes of objectives varied by region. Hazard reduction was the most highly rated objective except in the Rocky Mountain, Southern, and Eastern Regions. In the Rocky Mountain and Southern Regions, fire reintroduction and threatened and endangered species management, respectively, ranked slightly higher than hazard reduction. In the Eastern Region, four resource objectives were ranked higher than hazard reduction with game species management ranking the most important. Fire reintroduction was the second most important objective in the Northern, Southwestern, Intermountain, and Pacific Southwest Regions. Reforestation and non-game species management were second in the Pacific Northwest and Eastern Regions, respectively. Reforestation or game species management was the third most important resource objective in most Regions.

Per Acre Costs

Slash reduction burning had the highest estimated cost per acre (\$167.04) in six of the eight Regions (*table 1*). Prescribed natural fire (PNF) was the second highest, averaging \$103.68. The variability in (PNF) ranking was high, ranging from least expensive in some Regions to the most costly in others. Management-ignited burns averaged \$78.13 per acre and brush, range, and grassland burns were the least costly, averaging \$57.09.

Variation in Reported Costs

Differences between costs of different burn types reflect differences in blends of resource objectives, burning conditions, site characteristics, and management policies. Differences between slash and management-burn costs were greatest in the Pacific Northwest Region (\$334.02 - \$77.55 = \$256.47) and the Pacific Southwest Region (\$344.46 - \$223.38 = \$121.08), and were the lowest in the Southern Regions (\$42.34 - \$22.80 = \$19.54) and the Rocky Mountains (\$61.06 - \$58.24 = \$2.82). In the Northeastern Region, management-ignited burns were more expensive than slash burns by \$18.07 per acre.

There were distinctive differences within burn types. Slash burning ranged from an overall "lowest" of \$68.24 to an overall "highest" of \$330.72. The range (estimates of highest minus lowest) varied from \$594.40 per acre in the Northern Region to \$31.25 in Southern Region. The widest ranges for management-ignited prescribed burns were reported in the Northern Region (\$437.11 - \$37.56 = \$399.55) and the Pacific Southwest Region (\$356.98 - \$93.56 = \$263.42). The smallest range was reported in the Southern Region (\$30.73 - \$16.02 = \$14.71). The Rocky Mountain, Southwestern, and Intermountain Regions had similar ranges of about \$81 between the estimated highest and lowest costs. This variation reflects a wide range of site characteristics, post-harvest conditions, and multiple objectives among Forest Service harvesting and salvage units.

Table 1—Mean estimated average cost per acre and planning cost percentage for prescribed burning, in 1994 dollars, by National Forest System Region and burn type (1985-1994).

Region (Response/ surveyed)	Slash reduction		Management- ignited		Prescribed natural fires		Brush, range, and grassland		All types	
	\$ / Acre	Pct. in planning	\$ / Acre	Pct. in planning	\$ / Acre	Pct. in planning	\$ / Acre	Pct. in planning	\$ / Acre	Pct. in planning
1(12/13)	173.67	20.3	121.00	30.6	121.21	4.1	57.09	44.4	118.24	21.7
2(8/10)	61.06	15.6	58.24	19.0	-	-	38.81	30.0	38.53	20.4
3(11/11)	77.05	11.4	38.85	29.5	7.67	52.2	37.30	30.1	40.22	22.1
4(8/15)	81.34	16.0	34.88	24.9	133.50	5.6	19.83	37.8	67.39	13.6
5(15/18)	344.46	16.2	223.38	44.3	270.00	-	174.47	22.0	253.08	19.1
6(18/19)	334.02	19.3	77.55	42.5	85.97	35.1	55.82	48.2	138.34	27.9
8(13/13)	42.34	29.2	22.80	29.1	10.70	15.9	29.37	37.4	26.30	30.1
9(10/15)	45.60	21.9	63.67	20.1	22.00	22.7	29.38	10.6	40.16	19.3
Total (95/114)	167.04	18.9	78.13	34.4	103.68	10.5	57.09	30.3	101.48	21.3

Management-ignited prescribed burns were responsible for more acres burned than any other. Their cost would, therefore, drive any weighted-average regional or national estimate. The mean cost, \$78.13 per acre, was calculated from a regional mean of \$22.80 per acre in the Southern Region to \$223.38 per acre in the Pacific Southwest Region. The range between highest and lowest and the range across regional averages was much smaller than for either slash-burning or prescribed natural fires.

Prescribed natural fire (PNF) had the widest range in cost. However, because most Regions do not have an active PNF program, these estimates may not be reliable. They are based on 61 fires per year in which 2 Regions did not report any PNF's. The range in PNF costs varied from \$375.75 in the Northern Region to \$2.10 in the Southern Region. In Pacific Southwest Region, reports of the "average" and "lowest" estimates were the same in most forests.

Brush and rangeland burning costs varied from \$19.83 in the Intermountain Region to \$174.47 in the Pacific Southwest Region. The intra-Region ranges were the smallest of any burn type, except in the Pacific Southwest Region.

Cost Components

The largest portion of total costs (79 percent) for all burn types, was accounted for in actual project costs (*table 1*). Planning cost accounted for 21 percent of the mean, ranging from 11 percent for prescribed natural fires to 34 percent for management burns. The planning percentage was highest for PNF fires in the Southwestern Region (52 percent) and lowest for brush and range burns in the Northeastern Region (11 percent) and slash burns in the Southwestern Region (11 percent). Planning percentages were highest in the Southern (30 percent) and Pacific Northwest (28 percent) Regions and the lowest in the Intermountain (14 percent) and Pacific Southwest (19 percent).

Total Cost of the Burning Program

To estimate the total annual cost of the burning program in the responding forests, we multiplied treatment acres reported from each Region and burn type by mean per-acre costs. The total cost for burning the 908,180 acres per year was \$76.9 million (*table 2*), most of which was incurred by the Pacific Northwest Region (38 percent) and the Pacific Southwest Region (20 percent).

Most of the estimated cost was for slash burns (63 percent) and management-ignited burns (26 percent). Slash reduction costs in the Pacific Northwest represented more than one-half of the total cost for this type and more than one-third of the total cost for all types. The costs for prescribed natural fires and brush, range, and grassland burns were roughly even, each representing about 5 percent of the total.

Cost Factors

Fuels managers considered various factors to be important determinants of per-acre costs (*table 3*). In all Regions, unit size and the cost and availability of labor were the two most highly rated factors. Overall, safeguards to minimize escaped fires and compliance with environmental laws and regulations ranked third and fourth. Environmental laws received 3.0 and higher ratings in six of the eight Regions and was among the top four in the Northern, Southwestern, Pacific Southwest, Pacific Northwest, and Southern Regions. Escape safeguards received 3.0 and higher ratings in six Regions and was among the top four factors in the Northern, Intermountain, Pacific Southwest, and Northeastern Regions.

Two factors---availability of liability insurance and agency policies about risk-taking---received low ratings in all Regions. Satisfying multiple objectives, burn-unit shape, risks of liability, and residential development were also not highly rated overall but were each among the four most highly rated factors in at least one Region.

Table 2—Estimated total annual costs, in 1994 thousands of dollars, for prescribed burning activity on 95 responding forests, based on acreage and mean cost estimates, by National Forest System Region and burn type (1985-1994).

Region (Response/surveyed)	Slash reduction	Management- ignited	Prescribed natural fires	Brush, range, and grassland	All Types
1(12/13)	\$6,260	\$1,060	\$3,387	\$253	\$10,960
2(8/10)	181	209	-	206	596
3(11/11)	3,646	3,627	45	1,406	8,724
4(8/15)	327	147	291	99	864
5(15/18)	10,237	3,122	329	1,655	15,343
6(18/19)	26,495	2,396	1	248	29,140
8(13/13)	1,148	9,151	-	166	10,465
9(10/15)	165	558	13	96	832
Total	\$48,459	\$20,270	\$4,066	\$4,129	\$76,924

Table 3—Mean ratings of importance for 12 influences on the costs of prescribed burning, by National Forest System Regions (1985-1994) ¹

	R-1 Northern	R-2 Rocky Mountain	R-3 South- western	R-4 Inter- mountain	R-5 Pacific Southwest	R-6 Pacific Northwest	R-8 Southern	R-9 Eastern	All regions
No. of forests reporting/ No. of forests surveyed	12/13	8/10	11/11	8/15	15/18	18/19	13/13	10/15	95/114
Physical									
Size of the unit	3.58	4.07	4.00	3.55	4.00	3.44	4.52	4.00	3.92
Shape of the unit	3.00	1.97	1.64	3.36	2.57	3.06	3.67	2.40	2.83
Legal									
Regulations	3.42	3.23	3.82	2.91	3.43	3.06	3.48	2.00	3.21
Inputs									
Labor	3.25	3.43	3.45	3.55	4.50	3.33	3.90	4.00	3.69
Insurance	0.40	0.67	1.11	1.00	0.50	0.56	0.32	0.00	0.53
Risk									
Liability	3.25	3.40	2.82	3.45	2.82	2.50	2.95	3.00	2.98
Residential	2.67	3.37	4.09	3.00	3.29	1.50	3.19	2.70	2.90
Crew safety	3.08	3.30	2.91	3.64	2.71	2.94	3.05	2.60	3.02
Weather	3.50	3.40	2.55	3.91	3.21	2.82	3.12	3.10	3.17
Management action									
Objectives	3.17	2.43	2.91	3.27	3.21	3.33	2.43	1.70	2.83
Risk-taking	2.92	1.93	1.64	3.18	2.64	2.72	2.33	2.80	2.53
Escape safeguards	3.58	3.04	2.73	4.00	3.50	2.94	3.19	3.60	3.30

¹ Rating scale: 0 = no importance, 5 = highest importance.

The ratings profiles across the major categories—physical, legal, inputs, risks, and management action—were similar across the Regions and skewed toward physical (primarily size), inputs (labor), legal, and management action (escape safeguards). The most drastic differences in regional responses were in the risk category. For example, in the Rocky Mountain Region, three of the risk factors were among the most highly rated, but in the Southern Region, no factor in this category was similarly rated.

Discussion

Cost Estimates

Per acre costs seemed to be most influenced by unit size, although many factors, including the objectives mix and risk profile, interact to determine the final cost. This is consistent with results found in other studies of prescribed burning costs (Bell and others 1995, Dubois and others 1995, González-Cabán and McKetta 1986, Rideout and Omi 1995, Vasievich 1981, Wood 1988). Our study and Cleaves and others (1997) indicate that per-acre expenditures for natural-fuels burning have been decreasing in most Regions. This is attributable to more active and larger-scale burning, a growing awareness of cost determinants, and active programs to implement cost controls. As slash burning is reduced, FMO's may have to contend less with unit sizes and shapes that have been determined by harvest unit standards and guides.

Responses to our questions about project and planning costs were remarkably uniform, hovering at about 22 percent of the total cost in all the Regions. Because our definition of planning cost included activities that would normally be fixed, increasing burn unit sizes may decrease the impacts of planning on per acre costs in the future, *ceteris paribus*.

The responses show that prescribed natural fire can be expensive and variable. Substantial cost is incurred in monitoring PNF's and maintaining sufficient standby personnel to respond quickly to changing burning conditions. Although such fires are typically large, they require major commitments of fire fighting resources during times of high demands for these resources.

Comparisons with Other Data

Our total cost estimates were for the period 1985-1994. They do not reflect the cost of the burning program after 1994. Furthermore, they only show the costs of the 95 Forests that responded to the survey. We did not extrapolate to the entire National Forest System because we did not consider our nonresponses to be randomly distributed.

Our grand average for per acre cost is greater than inflation-adjusted expenditures from appropriated fuels (FFFP) and brush disposal (BDBD) funds for fiscal years 1980 through 1995 (Cleaves and others 1997, Schuster and others 1997). These are not directly comparable because these earlier reports were expenditure data, whereas ours were estimates from FMO's. However, some comparison highlights the complexities of accounting for and understanding burning costs.

For example, for the Management Attainment Report (MAR) Prescribed Fire (PF-2) class activity "natural fuels burning," which is analogous to Forest Service management-ignited burns, Cleaves and others (1997) and Schuster and others (1997) show expenditures of \$48.10 per acre. Our estimate was \$78.13. The proportional differences were similar for most Regions. Contrasts between these earlier reports and our estimates are as follows for each Region: Northern \$125.78 (\$121.00); Rocky Mountain \$80.06 (\$58.24); Southwestern \$31.28 (\$38.85); Intermountain \$101.39 (\$34.88); Pacific Southwest \$191.42 (\$223.38); Pacific Northwest \$192.72 (\$77.55); Southern \$10.97 (\$22.80); and Northeastern \$89.24 (\$63.67). The mean estimates in our survey were not weighted by acreage in burn types. Our rankings of regional averages were similar to those reported in the

earlier studies: the Northern, Pacific Southwest, and Pacific Northwest Regions were highest; the Rocky Mountain, Southwestern, and Southern Regions were the lowest.

Estimates in our survey include planning costs paid with funds other than FFFP and BDBD, including general overhead or other program functions. Project costs include those paid with funds provided by wildlife, range, and other benefiting programs. For example, about 273,000 of the 434,119 acres burned per year in the Southern Region had been funded with Knutson-Vandenberg (KV) funds, timber management, wildlife, range, other resource programs, and volunteered resources. This represents an additional \$3 to \$4 million not reflected in the Southern Region's Fire and Aviation Management obligations records and the corresponding acreage not listed as fuel treatment in MAR reports. We were not able to determine the extent of non-FFFP and non-BDBD in the other Regions. However, by comparing our survey with Cleaves and others (1997), we can identify Regions and roughly estimate the non-fuels funded acreage being treated.

Cleaves and others (1997) reported average annual BDBD-funded acreage at 361,757, whereas our study reported 230,131. Most of this discrepancy resulted from nonresponse; in the Intermountain and Pacific Northwest Regions a total of eight forest FMO's did not respond to our survey. The FFFP-funded (natural fuels) acreage in Cleaves and others (1997) was 336,460; our estimate was 677,989. Most of the difference was in the Northern, Southwestern, and Southern regions. The excess in the Northern Region reflected the use of prescribed natural fire, a burn type not recorded in MAR's. The Southwestern Region excesses, which totaled about 94,000 acres per year, were brush and range fires (37,677 acres) and, presumably, other fire activities not funded under FFFP. In the Southern Region, where we recorded 196,434 acres more than Cleaves and others (1997), the discrepancy was primarily because of burning funded by other benefiting programs, primarily wildlife and threatened and endangered species.

Although the FMO response rate was low in the Intermountain Region, our acreage estimates were close to those of the earlier studies. Greater response to our survey would have substantially increased the estimate of acreage not funded by fuels appropriation and BDBD. Several of the non-responding National Forests have well-publicized, natural-fuels burning programs of tens of thousands of acres per year.

Data Limitations

Data on costs were scattered and of variable quality. Survey responses primarily reflect subjective judgments and quantified data from a variety of record-keeping systems. Furthermore, the data is difficult to compare without knowledge of specific mixes and burn execution factors. Some of the FMO comments on open-ended questions in Cleaves and others [In press] provide additional insight into data quality, burning activity, and costs.

Comparisons among Regions should only be considered after extensive follow-up. There is great variation among responses within some Regions. These data comparisons should not be used to assert that one Region is more efficient than another. Each Region has a unique blend of resource objectives and physical, cultural, political, and economic cost influences. Understanding how those elements shape the cost of burning is critical to improving cost effectiveness.

There is an apparent need for a uniform data collection system to track cost trends and compare cost effectiveness of different burning strategies. This could be useful in guiding the allocation of costs to benefiting programs and in predicting costs with burn unit and other parameters (González-Cabán and Bednar 1990, González-Cabán and McKetta 1986).

There were few guidelines for collecting or analyzing cost data in the period of our study. Most uses of prescribed fire receive funding from several sources,

making information retrieval and consolidation difficult, and comprehensive estimates problematic. We received estimates from a variety of sources: subjective estimates, project burn plans, fire planning work sheets, Ranger District records, and district- or forest-wide rules-of-thumb. Subjective estimates reflect many forms of judgmental bias.

Our data collection process could be improved. Slash-burn cost estimates generally included the costs of machine or hand-piling and other preparation. Our crude categorization did not allow respondents to show different slash preparation and ignition methods, which may have been important sources of variation in the estimates. Also, there is some disagreement about what to include as "project" or "planning" costs, although most FMO's tried to conform to our categorizations. According to the respondents, planning cost estimates were less certain than estimates of project costs. Fire managers have less hands-on experience with overhead activity costs. Some admitted being very conservative in their estimates of this component, while others were as high as 70 percent. Some FMO's also said that the costs of planning were increasing because of requirements for comprehensive planning under NEPA, forest plan standards and guides, and environmental protection laws.

Cost Influence Implications

Several elements in our data suggest that burning costs could increase in the future. Cleaves and others [In press] reported that FMO's saw important barriers to increased burning in the form of funding availability, labor availability, and environmental restrictions. Despite fuels funding increases, labor availability may become critical, especially if an increasing wildfire control burden competes for trained labor.

The perceived importance of environmental restrictions was thought to be a reaction to a combination of factors: ambiguity in the application of regulatory standards; actual restrictions on burning practices; and reaction to the prospect of increasing regulations, the prospects of increased demands for NEPA environmental effects documentation, and potential legal actions. Many respondents felt that NEPA documentation and public scoping would delay burn projects and cause them to miss prescription windows. Some managers foresee an increasing NEPA burden because larger burns in natural fuels may require more elaborate analyses. There is little information about the current extent of NEPA analysis or how it adds to the cost and complexity of burning.

Conclusions

Prescribed burning is probably the most extensive planned disturbance activity in the National Forest System, a distinction formerly afforded to timber harvesting. Because burning supports a variety of resource objectives, its outlook is closely intertwined with the future of other programs, such as wildlife, threatened and endangered species, range, and ecosystem management. Success in these programs depends on the cost effectiveness of the burning program.

Ambitious burning goals are being pursued. Forest Service fire managers are gradually increasing the use of prescribed fire while holding down costs. Their responses in this survey reveal an awareness of and sensitivity to cost and cost factors. Their efforts deserve support. Fuel management budgets have increased dramatically, from historic levels of about \$20 million to \$60 million in 1997, but they recognize that this does not reduce the need to be cost effective. To meet burning goals, difficult trade-offs among resource objectives and funding sources will be necessary.

A uniform data collection system is needed to track cost trends and compare cost effectiveness of different burning strategies. This could be useful in guiding the allocation of costs to benefiting resource programs and in predicting costs with burn unit and other parameters. This data could also be used to guide

additional investigation into the constraints to implementing burning programs and enhance the further integration of land management planning and fire planning.

This data system should include a set of accepted criteria for indicators of burning performance at the program and project levels. The multiple-objective nature of burn prescriptions demands that such criteria be tied to resource management measures used to characterize desired future conditions in Forest plans. Measures of variability both in activity and costs could provide valuable perspectives on program performance. Ranges in costs for burn types within Forests could be assimilated into flexible performance targets and cost-effectiveness standards.

Activity data should be collected to allow stratification by fuel type, habitat type, and other resource management land-area categories, for a variety of burn types. The categories in this survey were too coarse to fully explain variations in cost, although they provided better information than the MAR data.

Cost data should not neglect planning costs. FMO's said they had trouble estimating those costs and, as a result, gave them less attention in making project or program decisions.

It is important to understand the reasons for cost differences among Regions, organizational units, or burn types. The data in this study should not be used to assert that one Region is more efficient than another. Each Region has a unique blend of resource objectives and physical, cultural, political, and economic cost influences. Understanding how those elements shape the cost of burning is critical to improving cost effectiveness.

There is also a need to better understand how political, managerial, and other forces influence the fire manager's behavior and the costs of burning. A more complete research design could better assess the relative importance of these factors and how they influence decision processes. One such factor is the shortage of qualified personnel. The burning season's narrow window of opportunity makes it doubly important that managers have a well-trained and available workforce. The role of environmental regulations could be better understood by conducting an assessment of the effect of laws and forest-level standards and guides. These effects could be researched as opportunity costs, similar to studies of harvesting and silvicultural investments made to comply with water quality best management practices.

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Session VII

Success Stories in Reducing Fire Management Costs

Chair: Armando González-Cabán

Wildfire Cost Reductions Through Equipment Development and Standardization¹

Richard J. Mangan²

Abstract

Standardizing equipment and clothing can reduce the costs of fighting wildfires by allowing items to be purchased in large quantities. In the U.S. Department of Agriculture, Forest Service, equipment is developed at two Technology and Development Centers, one in Missoula, Montana, the other in San Dimas, California. After a prototype has been developed, new items of equipment are tested in the field and completed with design specifications and drawings. The General Services Administration procures large quantities of items meeting these specifications, saving an average of 25 percent of the total cost. During the past 5 years, agencies have purchased about \$26 million in clothing and equipment each year, with savings of about \$6.5 million a year by purchasing through the General Services Administration.

When Ranger Edward Pulaski gathered his forces to battle the 1910 wildfires in northern Idaho, firefighters showed up with the clothes on their backs. Their tools were the basic hand tools they used on other forestry projects or those they used on other farm or woods projects.

Fire suppression in the 1990's operates in a different world. On September 9th, 1998, the *Missoulian* reported on fire fighting in northwestern Montana that summer. The fire camps were home to 4,847 firefighters and \$4.8 million worth of equipment, weighing 504,000 pounds. The equipment included: 189 pumps, 172 chainsaws, 1,700 sleeping bags, 7,600 sleeping pads, 4,100 Pulaskis, 2,500 shovels, 6,300 yellow shirts, 4,850 pairs of green jeans, 136,400 batteries, 63 miles of garden hose, and 128 miles of fireline hose.

Today, wildfires are a problem in Canada, Mexico, Mongolia, Spain, Australia, Siberia, and Greece, as well as the United States. Worldwide, wildfires are fought using essentially the same strategy and tactics, with equipment that is nearly identical. Regardless of a country's economic status, funding wildfire suppression operations is a major financial commitment.

Wildland fire equipment is part of the global economy. In response to major wildfire problems in the 1990's, fire equipment was shipped from the United States to Mongolia, Mexico, Indonesia, and to countries in South America. Multinational producers now make some items of wildfire clothing and equipment. The General Agreement on Trade and Tariffs, the European Union, and the proposed International Standards Organization standards on wildfire equipment will speed up international trade in wildfire equipment.

History of Fire Equipment Development

At the turn of the century, wildfire equipment development was an informal, backyard type of affair. Farmers, ranchers, and loggers developed equipment for their specific needs, often sharing their best ideas with neighbors. The Transfer Act of 1905 brought some focus in equipment development for the USDA Forest Service. Ranger Malcolm McLeod headed that effort. After Ranger Pulaski's heroic actions saved the lives of 35 firefighters during the 1910 fires, equipment development gained recognition. The fire fighting tool that gained popularity early in the 20th century was refined by Ranger Pulaski and took on his name. In 1912, a fire shield was developed that allowed fire fighters to get closer to a fire.

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In 1920, the Forest Service awarded the first commercial contract for production of Pulaskis. At the Mather Field Conference in 1921, Chief Forester William B. Greeley reported on the importance of inspections, physical inventories, and distribution of fire fighting equipment. An equipment standardization conference at Spokane, Washington, in 1936 brought additional focus to the issue of wildfire equipment development. By the 1960's, the Forest Service had established Equipment Development Centers in Montana and California. The Michigan Department of Natural Resources established a Forest Fire Equipment Center in Roscommon, Michigan.

Availability of Wildfire Equipment

Structural firefighters get their equipment almost exclusively from commercial manufacturers and suppliers. However, agencies that fight wildfires have many supply sources:

- All wildfire agencies regardless of size or affiliation can obtain equipment from commercial suppliers.
- Federal agencies and their cooperators (States and others) can purchase fire equipment through the General Services Administration (GSA).
- Several larger State agencies, such as the California Department of Forestry, manufacture their own wildfire clothing through organizations such as prison industries.

When larger fires require extraordinarily large amounts of equipment, nine national fire caches (eight managed by the Forest Service and one by the Bureau of Land Management) and two GSA warehouses are available. In addition, a fleet of fire cache trailers, each with enough equipment to support 250 firefighters, are located across the country. With the recent evolution of contract crews who are unable to buy supplies through Federal sources, several commercial suppliers have begun increasing their stocking levels during fire seasons.

Equipping wildland firefighters in Federal agencies is based on standardizing equipment so it can be used by all agencies. The firefighters who respond to multi-State wildfires take only two sets of protective clothing with them, exchanging dirty sets at the supply unit as needed. This closely approximates the direct exchange (DX) concept widely used by the military services of the United States.

Standardization and Quality Assurance

When the Forest Service's two Equipment Development Centers were fully chartered in 1960, Federal wildfire agencies started seeing the first benefits of equipment standardization on a large scale.

More and more wildfire equipment was developed at the Equipment Development Centers, tested in the field, and completed with design specifications and drawings. Afterward, equipment of consistent quality could be procured at the best price for the government.

Currently, the two Forest Service Centers (renamed Technology and Development Centers) are responsible for more than 200 design specifications. The GSA procures items meeting these specifications for Federal wildfire agencies, their State partners, and other cooperators. The equipment is distributed nationally and to other countries during emergencies.

How big has the program grown? In the 5-year period from 1994 to 1998, the total GSA fire equipment sales based on specifications and drawings produced by the two Forest Service Centers averaged nearly \$26 million per year. During 1994, when large fires burned throughout the western United States, sales topped \$34 million.

Standardization of wildfire equipment for Federal and State agencies achieved a new level of acceptance in 1993 when the first National Fire Protection

Association (NFPA) standard on wildfire protective clothing equipment was adopted in the United States. The standard, NFPA 1977, includes helmets, shirts, trousers, gloves, boots, and fire shelters. It sets minimum performance standards for wildland firefighters' personal protective equipment that enable commercial manufacturers and suppliers to offer products outside the GSA program. This standard, updated in 1998, helps ensure that all wildland fire agencies provide firefighters the minimum levels of protection from the dangers of wildfire.

Besides the NFPA standard in the United States, the Canadian General Standards Board has recently completed work on the first Canadian standard for wildland firefighters' personal protective equipment. In addition, the International Standards Organization is working on a draft proposed standard for wildland firefighters' personal protective equipment. That standard will have international standing under the General Agreement on Trade and Tariffs.

All the standards are important. They offer a needed level of protection to wildland firefighters while providing a "level playing field" for manufacturers and suppliers.

Cost Savings on Wildfire Equipment: The Federal Experience

Wildfire equipment procurement for Federal agencies and cooperating State agencies is a success story for the American taxpayer and for fire fighting agencies.

Design specifications prepared by the two Forest Service Centers are forwarded to the GSA wildfire program at Fort Worth, Texas. There, procurement contract specialists solicit bids, review a bidder's ability to deliver a product, and award contracts for a wide variety of clothing, tools, and equipment needed by the wildland firefighter. Because of the vast economies of scale provided by the GSA bidding process, manufacturers are able to offer their "most favored customer" rates on each solicitation, resulting in huge cost savings for the taxpayer. The GSA, as a semiautonomous government agency, charges an overhead fee on each item to offset its costs. Aside from the solicitation and contract actions, GSA provides quality assurance specialists at individual plants to ensure that design specifications are rigidly followed. They also maintain large fire equipment warehouses at Stockton, California, and at Fort Worth, Texas, for the short-term emergency equipment needs of fire agencies across the country, as well as for international support missions, such as those to Mexico and Mongolia in 1998.

Each year, the GSA publishes a catalog of wildfire protective equipment and supplies that is widely distributed throughout the wildland fire fighting community. Because each item has been standardized, fire fighting units have confidence that they will receive exactly what they request and that it will be fully interchangeable or adaptable with equipment already in the field.

Does all this standardization of equipment, coupled with volume purchasing, really result in cost savings? In 1997, a study compared prices in the GSA fire equipment catalog to those in catalogs for major forestry and fire suppliers (Ben Meadows, Forestry Suppliers, Mallory, and Darley).³ Prices charged by the four commercial suppliers were averaged and compared to the GSA prices to show the potential savings.

- Only one fire shelter is manufactured commercially in the world. It is built according to Forest Service specifications and sells in the GSA fire catalog for \$39.34. The commercial suppliers' average price is \$89.98, a difference of \$50.64. In Fiscal Year 1998, the GSA sold 28,370 fire shelters, saving fire fighting agencies \$1,436,567.
- In 1998 the GSA sold 27,888 fire shirts for \$43.43 each. These 5.5-ounce Nomex shirts were compared with 4.5-ounce Nomex shirts from

³Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.

commercial suppliers that cost an average of \$74.12. Savings in 1998 totaled \$855,883.

Across the board, fire fighting agencies save about 25 percent by procuring clothing and equipment through the GSA. Applying the 25 percent savings to the average annual GSA sales of \$26 million in fire fighting equipment results in an average savings of \$6.5 million each year.

Downside of Standardization

Although this paper strongly supports standardizing fire clothing and equipment, several aspects of standardization may be considered drawbacks.

Cost efficiencies realized through standardization are greatest when the products are the most widely used. This is especially true of clothing, where items are generally produced to meet the size needs of 80 to 90 percent of the general population. About 10 to 20 percent of firefighters fall outside that range. The needs of those who are very tall, short, heavy, or thin often are not met by standardized production runs. Fortunately, a solution exists. The wildfire supply community now has suppliers that cater to large or tall sizes.

A different situation exists for standardized equipment-hand tools and backpacks---used by wildland firefighters. Although standardized equipment may fully meet the firefighters' physical needs, it does not allow them to show their individuality. The proliferation of specialized hand tools---the Super P, the Reinhartski, and similar tools---and the myriad of firefighter field packs demonstrate that every individual seeks recognition. The cost efficiencies of fire equipment standardization are not important to those seeking to establish their identity in the wildland fire fighting world. I hope those firefighters will remain just a small percentage of the total work force.

Future of Fire Equipment Supply

What changes will the 21st century bring to the wildland fire equipment supply system? Will the year 2000 computer bug destroy all the gains in cost efficiency that have occurred in the past millennium?

Some predictions can be made about the future of wildland fire fighting worldwide:

- The problem of wildfires is increasing in scope and complexity.
- Today's essentially unlimited dollars at the Federal level will not continue to be available.
- Globalization of the fire suppression effort will increase, requiring standardization and the ability to interchange equipment.
- The General Agreement on Trade and Tariffs and future International Standards Organization standards will affect equipment procurement for wildfire agencies worldwide.
- Interagency cooperation at the national and international level will require standardizing equipment to assure maximum efficiency and safety for wildland firefighters.

Case Study of the Modified Fire Suppression Option: Three 1997 Alaska Fires¹

Kent Slaughter²

Abstract

Flexibility in the Alaska Interagency Fire Management Plan allowed for varied responses to three Modified fires, all located within 15 miles of Bettles, Alaska. Discussions with land managers about values at risk, potential cost, probability of success, fuels, and fire behavior resulted in the decisions to directly suppress two fires and indirectly suppress the third. The fires B347 and B483 were 45 and 400 acres at time of detection, while fire B349 was 600 acres. Fires B347 and B483 were held to 50 and 600 acres at costs of \$25,568 and \$202,893, respectively. Fire B349 grew to 24,185 acres at a cost of \$115,306. Aggressive attack of Fire B349 would have resulted in a similar or higher cost, while losing the ecosystem benefits of a large patchy fire in a fire-dominated ecosystem.

Introduction

This paper will examine the differing decision processes in the management of three fires that occurred in the Tanana Zone, Alaska, in areas designated for Modified suppression during the summer of 1997. The three fires were within 15 miles of Bettles, Alaska. Two fires, B347 and B349, started on June 21. Fire B483 started on July 3. The fires were responded to and managed in three separate methods available by using the Modified management option, demonstrating the flexibility of the Modified suppression option and the Alaska Interagency Fire Management Plan.

Alaska Fire Management

Wildland fire in Alaska is managed under a state-wide consolidated plan (U.S. Department of Interior 1982,1984). The plan has four management options for fire: Critical, Full, Modified and Limited. Each option has specific operational procedures designated in the plan, ranging from priority over other fires to procedures for when natural fire is desired or the values at risk do not warrant the expenditure of funds. Critical and Full call for immediate initial attack, while Limited calls for only the suppression necessary to protect sites or keep the fire within the management unit. Modified is intermediate between Full and Limited and has more possibilities for initial attack decisions.

Fire suppression duties are split between two Federal and one State agencies and are separate from most other land management responsibilities. Agreements between the State and Federal governments have divided the state by geographic region. The U.S. Department of Interior, Bureau of Land Management-Alaska Fire Service (USDI / BLM-AFS) has responsibility for most of interior and northern Alaska, regardless of the land ownership. The State of Alaska, Department of Natural Resources, has similar responsibilities for much of the rest of the state. The USDA Forest Service manages fire on its lands in southeast and south-central Alaska (*fig. 1*).

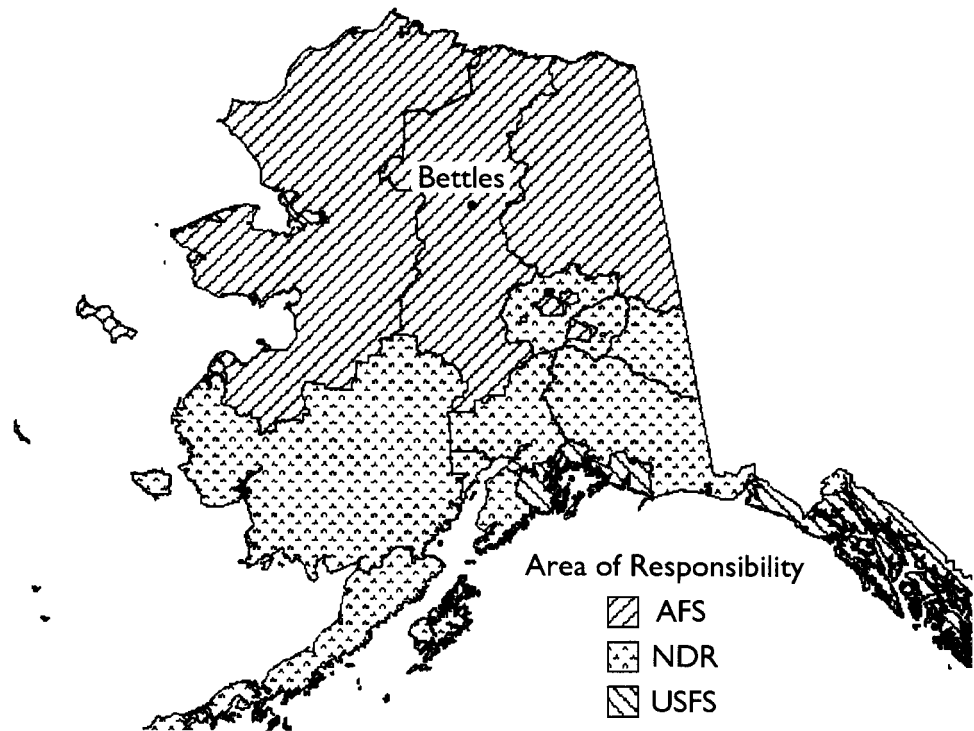
The Alaska Interagency Fire Management Plan (the Plan) was completed and implemented in 1984 (U.S. Department of Interior 1984). Before completion of the Plan, all fires were suppressed under a policy similar to the former USDA Forest Service "10 a.m." policy (Alaska Wildland Fire Coordinating Group 1998). Priority for suppression rested with fire managers and did not necessarily take into account the role of fire in the environment. Fire managers prioritized fires

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, and Policy: Bottoms Lines, April 5-9, 1999, San Diego, California.

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Figure 1

Location of Bettles, Alaska, and Fire Management Zones within Alaska. The three zones in the north are managed by the Alaska Fire Service (AFS), the zones in the southwest and south-central are managed by the State of Alaska (DNR), and the southeast is managed by the USDA Forest Service (USFS).



for resources. Some fires did not receive any suppression due to location and a lack of resources, but these decisions were not systematic.

If a Modified fire escaped initial attack, the Plan called for the preparation of an Escaped Fire Situation Analysis (EFSA). The EFSA involves analysis of costs and effects of various suppression or monitoring strategies. A strategy is picked by the land and fire managers that will meet their goals.

The Plan was drawn up with land managers fully involved. It took into account the role of fire in the environment (Viereck and Schandelmeier 1980), while putting more emphasis on involvement of the land managers in fire management decisions. Land managers are contacted about all fires on their lands and their wishes for suppression are taken into account during the operational phases of fire fighting.

The Plan was designed to evolve over time, with changes being made to the suppression levels for different areas as more information became available and land managers grew more comfortable with the Plan. Statewide between 1982 and 1997 about 5 million acres have been changed from Full to Limited, 10 million acres have been changed from Modified to Limited, and 7,700,000 acres have been changed from Full to Modified (Strong and Burrows 1998). Modified and Limited are the more flexible options, with Modified offering the most operational adaptability.

A 1998 revision of the Plan, the Alaska Wildland Fire Management Plan (AWFMP), consolidated and updated earlier versions of the Plan (Alaska Wildland Fire Coordinating Group 1998). The definition of Modified in this plan includes language specifying that it is the most flexible option and is intended to balance suppression costs with acres burned.

Narrative

The three fires in this study were lightning-caused and were reported by pilots. At the time of initial reports they varied from 1 to 10 acres, but by the time initial attack forces arrived they were from 50 to 500 acres in size. Initial locations reported by pilots and plotted by dispatchers were somewhat inaccurate, leading

to delays and possible changes in the management strategies for two of the fires. Information from the USDI BLM-AFS fire folders shows that one fire was managed as an initial attack smokejumper fire, one as an extended attack fire with smokejumpers and crews, and one as a limited action fire.

The initial attack fire, B347, was contained and extinguished by eight smokejumpers, with a final size of 50 acres. The limited action fire, B349, grew to 25,000 acres. The extended attack fire, B483, was held to 600 acres by 60 firefighters (*fig. 2*).

Fires B347 and B349

Both fires were reported in mid-afternoon on June 21, 1997, with approximate locations given by pilots. Initial plotting on protection maps showed them to be in Limited areas. Land managers were notified of the fires and the decisions to not staff them. BLM transport aircraft were used to update dispatchers on locations and burning conditions. As updated information arrived it became apparent that the early locations were incorrect.

The initial report on fire B347 was 1-2 acres, 90 percent active, mostly tundra fuels with rain showers in the area. Maps showed a creek and a cabin approximately 1 mile south. Based on this initial information, the AFS and State duty officers made the decision to not staff the fire. At approximately the same time another fire was reported in the same vicinity. The initial reports placed it in a Limited area, but updated reports gave different locations.

Corrected mapping placed both fires in Modified areas. The fire management officer flew both fires late in the evening. When he arrived at B347, it was actively burning on all flanks and did not appear catchable; but after sizing up B349 he returned to B347 and found that the fire had received considerable rain and that it could be caught. There were no apparent values at risk from B349 while B347 threatened a cabin. The decision to staff only one of the two fires was based on the fire sizes, probability of successful initial attack, limited availability of smokejumpers, and values at risk. He ordered initial attack resources for the second fire to be available early the next day in case resource protection was required and began the preparation of an EFSA.

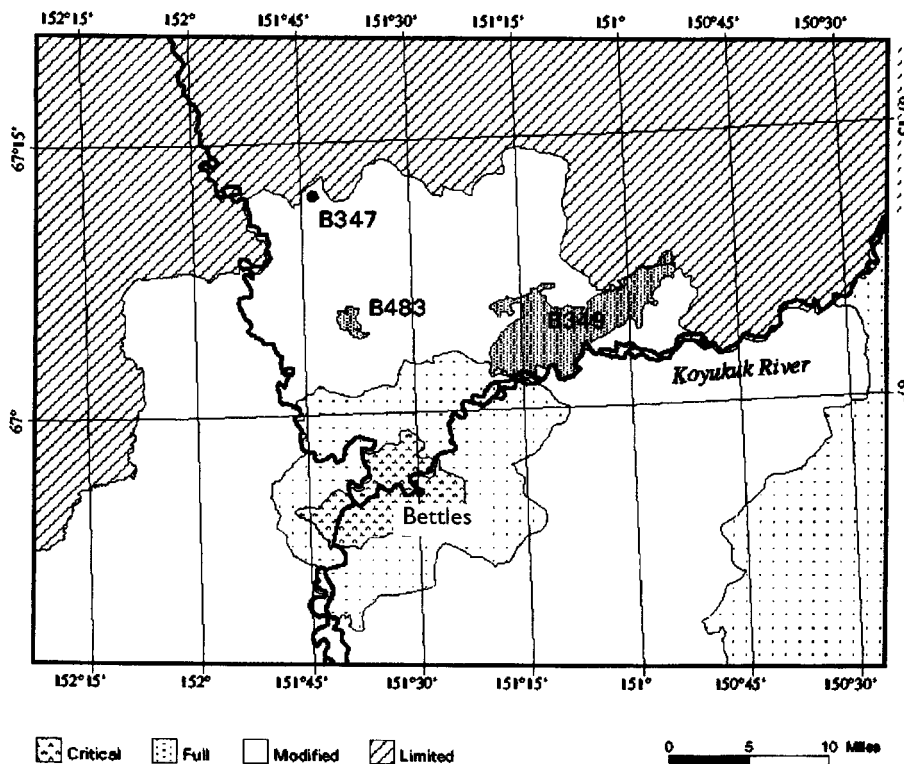


Figure 2

Fire management options (Critical, Full, Modified, and Limited) and locations of three 1997 fires (B347, B349, and B483) near Bettles, Alaska.

Fire B347 was caught by the eight smokejumpers who were dropped on the fire. Located near the boundary between Limited and Modified, it threatened a cabin about three-fourths of a mile away. It was declared out 3 days after it was found. There was no appreciable size growth from the time the smokejumpers landed until it was declared out.

On the morning of June 22, B349 was sized-up by smokejumpers. Based on their observations and initial conversations with land managers, it was decided to continue with monitoring. There were no resources directly threatened by the fire, it was only catchable with a sizeable commitment of resources, and the cost of trying to catch it was estimated to be high. An EFSA was started that day and completed on June 23. The fire was on State land, but was surrounded by lands owned by two native corporations, the BLM, and the National Park Service. Representatives from all the land owner/ manager agencies were involved in the EFSA process and concurred with the final management decision.

Four alternative action plans were identified in the EFSA for B349.³ The alternatives were: no action, place crews on the fire, and two different limited actions with aerial firing. A limited action to use aerial firing and the natural barriers of the Koyukuk River and a creek was chosen as the preferred alternative by land managers. The plan would protect resources to the south and west at a reasonable cost. The estimated cost was \$75,000 with led to a cost of \$115,306 and a size of 24,185 acres.

The fire was monitored daily and its growth mapped by AFS staff. Based on the growth, projected weather, fuels the fire was burning in, and the preferred perimeter identified in the EFSA, the decision was made on June 26 to send a light helicopter with a burn boss and aerial ignition device operator to burn out on the southern and western flanks. The plan was to keep the fire out of Full areas by burning along a creek and the Koyukuk River. This was accomplished over the next two days, except for one spot fire on the western flank. The decision was made to let the spot fire grow for the time being based on fuels, access, and weather.

At this time the fire was just over 20,000 acres and had cost an estimated \$20,000. The fire had been monitored and limited action taken to keep it from burning out of designated control lines. The Plan was followed and the multiple goals of keeping fire out of high value areas while allowing it to play its natural role in the environment were met.

Eighteen days after the fire started 3 crews were placed on the spot fire on the west flank for 3 days. The crews mopped up the edge of the spot fire, with the goal of keeping the fire from moving any more to the southwest and into areas designated as Full. These crews were from an adjacent fire, B483, and were moved to B349 because they were available and seen as a low cost method of meeting the land managers' goals. The fire was monitored for 12 more days before it was declared out.

Fire B483

Fire B483 was an extended attack fire that started on July 3, 1997. Crews and smokejumpers were ordered simultaneously, with smokejumpers arriving first. The fire was in an area designated for Modified protection. It was 50 acres when detected, 100 acres when the smokejumpers arrived and 600 acres when it was declared out. At the time of detection and the decision to staff the fire, the land manager was not available but later concurred with the decision. The decision was made due to the proximity to areas designated for Full protection, a lack of natural barriers between the fire and Full areas, and the Plan, which calls for initial attack in Modified areas early in the season.

Resources available for the initial attack were limited. One load of smokejumpers were available in the state. Before their departure to the fire, the smokejumpers were briefed over the phone by the fire management officer about objectives, resources available, and the plan to send hand crews. Several hand

³Unpublished data on file, Alaska Fire Service, Bureau of Land Management, U.S. Department of Interior, Ft. Wainwright, Alaska.

crews, two helicopters, and retardant were ordered. Another start close to Fairbanks that same day diverted some of the ordered resources.

The extended attack suppression efforts were successful. Managers of adjacent lands were informed of the fire and the suppression decisions in case it escaped initial attack. There was close communication between the Tanana Zone fire management staff and the incident commander on tactics, resources and goals. The fire was contained, mopped up, and declared out in 6 days.

Different Approaches to the Fires

There were seven primary factors that went into the decision processes that resulted in different fire management strategies for these fire: size upon discovery, plotted location, resources available for suppressing the fire (both initial attack and extended attack), threats to development or high value resources, fire behavior, the projected cost of suppression, and the flexibility of the Modified option.

Size Upon Discovery

B347 and B349 were both reported as small, 1 acre fires, while B483 was reported as a larger fire. B347 was over 40 acres and B349 was over 400 acres when viewed by the AFS fire management officer. Size was a factor in the decision to suppress B347 and not to suppress B349, but it did not play a role in the decision on B483.

Plotted Location

The misplots of B347 and B349 were very important to the initial decisions to not suppress them when initially reported. Being misplotted led to a significant delay in the decision process and resulted in the delayed initial attack on B347 and the decision not to use initial attack on B349. If they had been correctly plotted both might have been initial attacked at an earlier stage.

B483 was correctly plotted. The timely response to this fire and decisions on resource ordering were based upon correct plotting, indicating no natural barriers between the fire and Full suppression lands to the south.

Resources Available

At the time B347 and B349 were correctly located, there were limited resources available for immediate initial attack. The decision was made to use those resources for the fire that more directly threatened an identified resource (a cabin) and where the chances for success were higher.

B483 was suppressed by using the available resources. At the time smokejumpers were ordered for B483 they were the last load available in the state, and their use on a Modified fire had to be negotiated. Some of the resources ordered for B483 were diverted to a higher priority fire that started after B483.

Threats to High Value Resources

B349 threatened no high value resources at the time it was initially mapped, while B347 and B483 posed threats to high value resources. B347 was less than a mile from a cabin and potentially threatened the cabin. B483 threatened Full areas and a reported cabin. The threat to higher value areas to the south and west drove the EFSA decision on B349 to use the Koyukuk River and a creek as boundaries.

Fire Behavior

Differences in fire behavior contributed to the decision to suppress B347 and not B349. When first observed by the fire management officer, B347 was burning actively on all flanks. B349 was also very active and in heavier fuels. A short time later B347 was less active due to scattered rain storms that missed B349. This led

Table 1—Estimated costs and sizes for four management alternatives, Fire B349.¹

Management alternative	Estimated size, acres 72 hours	5	Estimated cost (Dollars)
Monitor from air	1,200	n/a	5,000
Direct attack with crews	1,000	1,000	125,000
Aerial fire between Wild River and Koyukuk River	n/a	70,000	20,000
Aerial fire between Mud Creek and Koyukuk River	n/a	0	75,000

¹Unpublished data on file, Alaska Fire Service, Bureau of Land Management, U.S Department of Interior, Ft. Wainwright, Alaska.

the FMO to use smokejumpers for B347 because he felt initial attack would be successful on it, but would not be successful on B349.

Fire behavior did not play a role in the decision to suppress B483 but did have an effect on the manner in which it was suppressed. During the first burning period, crews were held in the staging area rather than sent directly to the fire while a safe area was secured. After this period additional crew orders were canceled because of decreased fire activity.

Projected Costs

The projected cost of suppression was a formal part of the decision process for B349 during the writing of the EFSA. The projected cost of each alternative was determined based on known costs and assumptions about the duration of each alternative (*table 1*). Because the least cost alternative did not meet integrated management objectives, a higher cost alternative was chosen. The decision to transfer crews from fire B483 to fire B349 took into account that the government was already committed to the cost of transporting the crews home and refurbishing their equipment. These costs were transferred from B483 to B349, but were already incurred. The only additional costs were wages, food, and helicopter flight time.

Flexibility of Modified

The objectives of Modified within the Plan were: reduced suppression costs through minimum force and indirect tactics; and use of fire to achieve land management objectives. This allowed fire managers to choose direct suppression, as on B347 and B483, or a combination of monitoring, indirect and direct suppression, as on B349.

Results of the Decision Process

There were three primary results from the decision process used on these fires: the suppression strategy followed on B349 resulted in a cost savings over other possible strategies; the fires were managed in accordance with the Plan and the Federal Fire Policy; and discussion on changes in the land status near B349 were initiated and no changes resulted.

Savings on B349

The actions taken on B349 after it was correctly plotted resulted in a significant cost savings, while maintaining fire in the landscape. By the time resources were available on June 22 the fire was over 600 acres and in heavy fuels. A reasonable cost for direct suppression of a 100 to 1,000 acre fire in interior Alaska is between \$125 and \$400 per acre (Strong and Burrows 1998). Final size under a direct suppression strategy was estimated at 1,000 acres. This would have resulted in a cost of over \$125,000 and could easily have cost over \$250,000. No high value resources were directly threatened. The final fire burned 24,185 acres at a cost of

Table 2—Costs associated with three 1997 Alaska fires.¹

	B347	B349	B483
	1997 U.S. dollars		
Wages and benefits	15,706	55,232	97,482
Aircraft and vehicles	7,830	58,595	56,172
Materials and supplies	1,976	633	47,744
Other	56	846	1,495
Total	25,568	115,306	202,893

¹Unpublished data on file, Alaska Fire Service, Bureau of Land Management, U.S. Department of Interior, Ft. Wainwright, Alaska.

\$4 per acre (*table 2*). The use of natural barriers and low cost aerial ignition to burn out along those barriers allowed fire managers to keep costs low.

The placement of crews on B349 increased the cost of the fire from \$20,000 to \$115,306. The Zone fire management considered not placing any crews on the spot fire, but decided that the availability of the crews from the adjacent fire would allow a limited action within the EFSA guidelines at a relatively low cost (Strong and Burrows 1997, 1998).

Compliance with Plan

The three fires were managed within the guidelines of the Plan and the 1996 Federal Wildland Fire Management Policy and Implementation Action Plan (U.S. Department of Interior/U.S. Department of Agriculture 1996). Both the Plan and the Federal Policy, written a decade after the Plan, reflect recognition of the appropriateness of different levels of suppression and the role fire and suppression play in maintaining healthy ecosystems.

The different suppression efforts were within the range identified in the Plan. The Plan calls for immediate, aggressive suppression on all fires in Critical and Full and in Modified early in the season. This was followed for fires B347 and B483. Fire B349 was managed as an escaped fire due to the initial lack of resources and the low threat it posed to high value resources.

Ecological management goals were addressed with the Modified management strategy adopted for B349. The fire was managed in such a manner that high value areas to the south and west were protected, while low value areas to the north and east were allowed to burn.

Land Status

As part of the EFSA process, the National Park Service requested that the appropriateness of Modified for the area of B349 be reviewed at the end of the season.⁴ An informal process was started by the Zone staff, but no changes were suggested by land managers (Strong and Burrows 1998).

Applicability to Other Areas

The Plan and the management of these fires under the Plan offer ideas applicable to other areas: guidelines for joint fire management of fragmented ownership can work well; flexibility in a fire management plan allows resource management goals to be accomplished; and monitoring and indirect attack can be effective management tools that realize cost savings.

Guidelines for Joint Management

The Plan provides guidelines for land and fire managers to work together. The separation of fire management from land management and fragmented ownership have necessitated that these methods be developed. The EFSA provides a simple, coherent method for land and fire managers to jointly consider their options for fires that escape initial attack. The land managers may also call

⁴Unpublished data on file, Alaska Fire Service Bureau of Land Management, U.S. Department of Interior, Ft. Wainwright, Alaska.

for reconsideration of suppression actions taken by fire managers. The Plan calls for annual review of the suppression status by land and fire managers. In practice this has often meant that fire managers have taken the lead and suggested areas for review each winter.

Flexibility

The Modified option is intended to reduce suppression costs and increase resource benefits during the entire fire season and ensure that suppression costs are commensurate with values at risk. This is accomplished by three primary methods: initial attack is used early in the season, indirect attack and site specific attack are used throughout the season, and late season fires are monitored. Land managers may request that initial attack be an indirect effort or that there be no initial attack.

The sparse settlement pattern and scattered resources of interior Alaska allow managers a great degree of flexibility in their fire management decisions. Priorities for suppression are designated in the Plan, and large areas may be designated for Modified and Limited suppression. This could be applied to some higher density areas, although it is doubtful that managers could be as flexible in allowing fires that escape initial attack to grow as large as B349.

Monitoring and Indirect Attack

The monitoring and indirect attack methods used on B349 resulted in significant savings when compared to the projected cost of direct attack. Taking only the actions needed to protect high value areas allowed ecological processes to continue relatively unimpeded. Managers in other areas may not be able to monitor and use indirect attack as much because of high densities of resources, but it can be considered as a method for lowering costs.

Conclusion

The Modified suppression option worked to allow flexible management of three closely located fires in interior Alaska during the summer of 1997. The goal of the Modified suppression option is to balance suppression costs against values at risk and ecological benefits of fire. Fire managers were able to do this through consideration of values at risk, resources available, fire behavior, and projected costs of suppression. Based on these factors they chose to direct attack two of the fires and use indirect and limited direct attack methods on the third. The combination of methods allowed resource management goals to be met while protecting high value resources.

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Efficiency Through Interagency Planning¹

Robert J. Leighty,² Robert P. Blume³

Abstract

Current information is presented detailing the interagency fire management planning efforts between the Bureau of Land Management's Grand Junction District and the USDA Forest Service's White River National Forest. The project is based on interdisciplinary input from an interagency pool of resource specialists and line officers. Landscape scale plans are displayed by using geographic information systems. Planning outputs are then used by various parts of the organization, including pre-planned suppression resource assignments used by incident dispatchers; a range of appropriate management responses available to initial attack incident commanders; identification and display of areas for priority fuels management expenditures; use of wildland fire to meet resource management objectives under prescriptive guidelines; linking fire management implementation and management direction in land/resource management plans; and input to out-year program planning development in an interagency framework via the National Fire Management Analysis process.

This paper provides an overview of interagency fire management planning efforts between the Bureau of Land Management's (BLM) Grand Junction District and the USDA Forest Service's (USFS) White River National Forest in western Colorado. These units administer in excess of 4.5 million acres of public land roughly situated parallel to the headwaters of the Colorado River and extending west of the Continental Divide to the Utah border.

The affected area is occupied by vegetative cover types stratified by an elevational gradient from 4,000' to 14,000' mean above sea level. Cover types include high desert grass and shrub communities, pinyon-juniper, and mixed brush species at lower elevations. Mid-elevation communities include Douglas-fir and ponderosa pine as well as mixed brush species. Upper elevations include aspen and lodgepole pine as seral or climax species as well as Engelmann spruce and sub-alpine fir that occupy higher elevational sites below timberline.

Before European settlement in the mid-1800's, wildland fire was primarily attributable to lightning, although some anecdotal accounts indicate that Native-Americans used fire to move game. European settlers introduced fire on a larger scale than their Native-American predecessors through land clearing, livestock grazing, and logging operations. These human-caused fires occurred in large part at lower elevations with fire spread upslope into timber cover types. Current vegetation in areas where mining activity was concentrated around the turn of the century show signs of large scale fires attributable to human-caused ignitions.

Current stand conditions can be characterized as mature to over-mature. A complex set of factors including climate, fire occurrence, insect and disease outbreaks, and human influence over the past 150 years have contributed to this situation. Prior agency fire policy that emphasized aggressive fire suppression undoubtedly influenced current vegetative conditions but to a lesser extent than other lower elevational areas where fire was a more frequent visitor on the landscape.

Relationship to Land/Resource Management Plans

All lands within the planning area were categorized on the basis of fire's historic role in the ecosystem and present/projected values at risk. Five categories of

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management response were developed to describe the desired role of fire within the planning area.

Category A consists of the management response that wildland fire in any form is not desired; fire has never played a significant role in the function of the ecosystem; or because of human development and/or habitation, it can no longer be tolerated without significant economic loss and social impact. All forms of wildland fire will be actively suppressed. Prescribed fire is limited in application for the sole purpose of reducing an immediate threat to firefighter and public health and safety. Unit costs for prescribed fire are prohibitive in many cases and are less efficient than other treatment methodologies such as mechanical treatment.

The management response of category B focuses on fire playing a natural but limited role in the function of the ecosystem. This response is based on resource concerns and potentially high economic impacts that may result from unplanned ignitions. Considerable constraints and mitigation are required to avoid unacceptable results. Fire suppression actions are generally aggressive. Fuels treatment and hazard reduction have priority over other forms of prescribed fire projects. Prescribed fire unit costs are high and require stringent contingency planning and monitoring.

Category C focuses on fire as a desirable component of the ecosystem. Minimal mitigation requirements and constraints are applied relating to ecological and resource management concerns. Firefighter health and safety considerations are used in determining the appropriate suppression strategy or strategies to be applied. Prescribed fire would be expected to help attain or maintain desired resource and ecological conditions. Planned ignitions focusing on hazard reduction are a lower priority than those described in category B. Unit costs and complexity for prescribed fire projects are low to moderate.

Category D consists of fire as an integral part of the ecosystem. Unplanned ignitions may be managed for designated areas where an approved Wildland Fire Implementation Plan (WFIP) provides for this form of management strategy. Minimal mitigation and ecological constraints apply. Use of planned ignitions to maintain desired resource and ecological conditions is appropriate. Prescribed fire for hazardous fuel reduction is not a priority except where an immediate threat to public health and safety exists.

Category E focuses on non-jurisdictional lands, such as in-holdings and adjacent private lands outside jurisdictional boundaries, as generally subject to an aggressive suppression response from responsible agencies. Hazardous fuels treatment projects may be undertaken on Federal lands in support of treatments on adjacent private lands in applicable cover types. Large contiguous areas that typically do not support wildland fire or the spread of fire to adjacent areas are included.

Wildland Fire Use (WFU)

A key objective of the planning effort was to identify wilderness and non-wilderness lands where unplanned ignitions may be managed to attain or maintain desired ecological conditions under prescriptive guidelines.

Designated Wilderness Areas (managed by the USFS) and Wilderness Study Areas (managed by the BLM) have been prioritized for development of WFIP's. These areas offer the best chance for management of unplanned ignitions on a significant scale, which will help in attaining resource management objectives. Surrounding non-wilderness lands have been incorporated into these planning areas on the basis of topography, local weather, and the historic role of wildland fire.

Incorporating these lands is designed to address the inherent limitations of managing unplanned ignitions located in close proximity to, but outside of, wilderness boundaries, as well as those ignitions that have a high probability of spreading outside the wilderness because of local topography and expected fire

behavior. The ability to use prescribed fire to "armor plate" portions of the perimeter of these planning areas is not constrained by the limitation of administratively designed boundaries that in many cases are located at midslope or other locations not conducive to management of a wildland fire incident.

The designation of an area for wildland fire use does not imply uniform application of the concept over all affected lands. Areas subject to infrequent large-scale wind-driven crown fire events may have limited applicability for management of an early season ignition because of the proximity of adjacent private lands. Conversely, use of planned ignitions to achieve age class diversity in timber cover types may be a useful tool to accomplish resource management objectives over the long term while addressing public safety and protection of improvements on adjacent non-jurisdictional lands.

Appropriate Management Response

The use of information on the historic role of fire in the ecosystem, current and pending land and resource management objectives, public and resource specialist input, fire behavior predictions, and agency fire management policy has resulted in designating a range of appropriate suppression response(s) for management of wildfires on affected public lands.

The hazard, risk, and value components of the Colorado Statewide Fire Assessment were used as the initial fire management inputs in the land management revision process at the unit level. Refinements to this geographic information system (GIS) data layer were developed by resource specialists and fire managers on the basis of local knowledge and resource management direction.

Interdisciplinary input was developed on an interagency basis to allow resource specialists to better integrate their input and to develop compromises where appropriate. As a result, potential problems of diametrically opposed agency-specific resource management objectives were avoided. In general, the BLM is responsible for management of public lands at lower elevations while the USFS is responsible to manage lands at higher elevations.

Clearly, using a contain or confine strategy downslope of an area where a control strategy is desired would be incompatible and subject to unequivocal failure in implementation. For instance, an incompatible situation would consist of an area of decadent sage and mixed brush situated downslope from an area proposed for treatment via a timber sale. Managing an unplanned ignition downslope of a high value resource using a less aggressive suppression response would meet the management objectives of one agency, but not the other.

The same principle was applied on a watershed basis or landscape scale where in general, the boundaries of category D should not be located downslope or directly upwind of lands designated as category A.

Interagency initial attack resources are responsible for the initial size-up and determination of fire cause for all wildland fire starts. Upon determination that the incident is a human-caused start, prompt and aggressive suppression action is undertaken to control the fire. When the fire is lightning caused, the fire manager and line officer discuss the range of available alternatives and direct suppression resources to implement the appropriate management response.

Pre-planned Suppression Response

Interagency dispatchers and unit fire managers continuously work to refine pre-planned suppression responses on a daily basis by considering baseline direction developed in response to resource management direction and the combination of key factors that may influence the probability of the success in implementing the designated response on a short term basis.

In high desert, grass-mixed shrub fuel types designated as category C, use of a low cost, less aggressive suppression strategy such as contain or confine may be appropriate to meet resource objectives, minimize suppression costs and

associated resource value loss. Initial attack resources may include an air attack and one or more engine crews but typically would not involve an airtanker, smokejumpers, or helitack.

Through daily discussions, the status of local resource allocation, number of fire starts, current and expected weather conditions, and associated fire behavior are addressed and used to amend pre-planned suppression responses as appropriate to the short term situation.

Out-Year Program Planning

Contributing to the accomplishment of resource management objectives through the use of planned and unplanned ignitions is in part based on the future desired condition of vegetation components as identified by interdisciplinary resource specialists. The ability to accomplish this level of resource outputs through planned ignitions relies on the availability of adequate staffing and funding through agency specific budget processes.

Both permanent staffing in fuels management as well as the availability of personnel for ignition, holding, and contingency resources are closely tied to the National Fire Management Analysis (NFMAS) process. Use of suppression resources to accomplish these management objectives on an interagency basis provides a significantly larger pool of resources than relying on the staffing available exclusively through either the Forest or District by itself.

Recent agency direction to use interagency resources without regard to reimbursement on a project or fiscal year basis provides more expertise and organizational depth to undertake a larger program than traditionally implemented on an agency-specific basis. Use of interagency resources on a closest forces basis has resulted in a significant improvement in providing timely and cost-efficient suppression actions as well. At the local level, this has been implemented by using several methods, including dispatch of the closest suppression resource regardless of agency affiliation; interagency staffing of engine crews and helitack; and interagency functional management and oversight in supervising personnel, planning suppression strategies, and preparation of required documentation, including Wildland Fire Situation Analysis (WFSA), incoming incident management team briefing packages, and fire behavior analysis.

Summary

In the examples cited above, both the BLM and USFS were better able to develop effective land and fire management plans by working together on a broad landscape basis across jurisdictions. The pooling of personnel and technical skills has yielded both implementation plans and organizational efficiency to better meet the changing goals and objectives of fire management in the 21st century.

Improving Wildland Fire Situation Analysis (WFSA) Implementation Practices¹

Donald G. MacGregor,² Armando González-Cabán³

Abstract

Federal fire management agencies are required by policy to conduct a Wildland Fire Situation Analysis (WFSA) for all fire incidents that have not been suppressed by initial attack efforts. A survey-based study of senior fire and natural resource managers revealed that while the process is generally regarded as a valuable one in fire management decision making, contextual factors can compromise the quality of its implementation. The frequency of WFSA fires is relatively low in most National Forests, often less than once or twice a year, thereby leading to a decline in the quality of WFSA skills. Lack of WFSA training, lack of fire experience and limited availability of information needed for the WFSA, among other factors, also contribute to poor quality WFSAs. More training as well as reinforced training are needed to maintain line officer and fire staff WFSA fluency.

Introduction

Management and suppression of wildland fires that have escaped initial attack pose significant challenges to the decision-making skills of land management administrators, such as district rangers and forest supervisors. Good decision making in managing wildland fire requires, at a minimum, the development of strategic options, identification of criteria for evaluating options, and assessment of costs and potential damages to the natural resource base. In addition, trade-offs must be made between costs and effectiveness of alternative suppression strategies, varying in likelihood of success or failure. Finally, decisions must be communicated to others and justified prospectively in terms of their logic and soundness, and retrospectively on the basis of actual outcomes.

A process that provides a key support component for wildland fire decision making is the USDA Forest Service's Wildland Fire Situation Analysis (WFSA, previously known as the Escaped Fire Situation Analysis [EFSA]). After a fire has been declared escaped, the line officer is mandated by agency policy to organize and implement an appropriate suppression response based on a WFSA. A WFSA must be completed for all escaped fires that continue into the next burning period.

According to policy stated in Forest Service Manual 5132, the WFSA is a multi-step, decision support process that requires identification of evaluation criteria, development of suppression strategies, and analysis of suppression alternatives. The alternative with the minimum suppression costs plus resource damages, consistent with the best expected probability of success/failure, is identified and implemented. In essence, the WFSA provides a framework based on a combination of principles and guidance from the decision sciences, including decision analysis, multiattribute decision making, and natural resource valuation.

Although agency policy is relatively clear about the conditions required for the completion of a WFSA, the context in which a WFSA is done is complex and demanding. The WFSA is conducted only if initial attack efforts have failed to achieve suppression goals, often after 1 or 2 (or perhaps more) days of continued suppression efforts. As the initial attack phase of an incident continues, greater local resources are often dedicated to the fire. By the time a decision is made that local suppression resources are insufficient to control the incident, many of the fire management personnel of the land management unit are already in the field and have been working diligently for long hours. Thus, the WFSA is often

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conducted in an atmosphere of defeat. Since fires often exceed initial attack efforts late in the afternoon, the decision to declare the fire escaped occurs late in the day. Very often, the WFSA is prepared either late at night or in the early hours of the morning. By that time, most of the personnel needed to do the WFSA are either on the fire site and/or are severely fatigued. According to policy, the WFSA is prepared by a team under the direction of the local line officer. The team includes both fire and natural resource specialists whose goal it is to complete the portions of the WFSA relevant to their areas of expertise. Ultimate responsibility for conducting the WFSA rests with the local line officer. However, the success of the WFSA process rests in part on the ability to bring together the required expertise in the time and place required. Often, this is difficult (or even impossible) to do when many of the staff required are on the incident scene. Thus, the WFSA process itself places significant demands on local human resources at a time when they are both reduced and minimally available.

Reactions from the field regarding the WFSA process have been critical: the process is cumbersome, and takes too long to perform under the time-pressure conditions of an ongoing large wildfire. However, we have to date no systematic study of how the WFSA process is perceived and what its shortcomings might be in the context of actual fire management situations.

The purpose of this study was to examine the experiences of senior fire management and natural resource management personnel with the WFSA process, to gain insights regarding how the WFSA has been used as a support for decision making in fire management, and to understand better the causes of poor quality WFSA's and possibilities to improve the WFSA process.

Methodology

The study was conducted by using a combination of interview and survey research methodologies. Structure for the interviews was provided by a set of key questioning points based on the WFSA process, including its perceived value in fire management, availability of natural resource values, usability of land management plans for the WFSA process, level of precision of probability assessments, factors contributing to poor quality WFSA's, and potential improvements to the WFSA process. About 2 to 3 weeks after the interview, each informant received a follow-up survey that probed key variables based on the interviews.

Informants for the study were senior fire management personnel, resource specialists, and agency administrators drawn from all five Federal fire management agencies: USDA Forest Service (USFS), USDI Bureau of Land Management (BLM), USDI National Park Service (NPS), USDI Bureau of Indian Affairs (BIA), and USDI Fish and Wildlife Service (FWS). The geographic area of the study included the six western USDA Forest Service Regions (Regions 1 through 6) in the contiguous United States.

All informants were directly involved in fire management for most (if not all) of their careers. Although many of the informants held (or had held) line officer positions, and were therefore directly responsible for conducting a WFSA, others had never held a line position, but had been involved in WFSA as part of, for example, a fire staff or as a member of an incident management team.

A total of 71 informants were included in the study; all five Federal fire management agencies were represented:

Agency	Number of Informants
USFS	52
USFS/BLM (jointly)	4
BLM	5
BIA	4
NPS	3
FWS	3

The set of informants represented a broad base of experience and resource management situations. In addition, line officer positions were also represented, including both forest supervisors and district rangers. All of the informants were experienced in WFSA and had been responsible for or participated in at least three to four WFSAs in their career. Some informants had participated in more than 25 to 30 WFSAs, most often in their role as a line officer or as a member of an incident team.

Results

Fire and WFSA Frequency

Study informants were asked to estimate the yearly average fire frequency in their land management unit, as well as the yearly average frequency of escaped fires requiring a WFSA. Both estimates were made as "best guesses" based on each informant's experience in their respective land management unit. Because the study was conducted in a wide range of land management regions, it was expected that there would be considerable variability in fire frequency. At the USFS forest level, estimated yearly mean fire frequency ranged from a low of about 25 for some National Forests in the Rocky Mountain Region (Region 2) to a high of 500 or more for some National Forests in the Southwestern Region (Region 3). For other Federal fire management agency informants (i.e., USDI BLM, BIA, NPS, and FWS), estimates were generally lower, primarily because their respective land management units were either in less volatile fuel types, less susceptible to ignition events (e.g., lightning), or the land management units were considerably smaller. In making yearly average fire frequency estimates, all informants noted the tremendous variability in the number of fires from year to year.

Informants were also asked to estimate the yearly average number of WFSAs on their land management unit. This proved to be a much more difficult estimation task, primarily because WFSAs occur very infrequently and year-to-year variability is quite high. Informants typically estimated WFSAs to be 1 or 2 percent of the total fires each year. However, when probed to recall specific WFSAs on their land management unit in the past 3 to 5 years, the number of WFSAs recalled was typically less than 1 percent of their estimates of yearly average fire frequency. Estimates of the actual number of WFSAs on a yearly average basis *at the forest level* ranged from a low of 0.1 (one WFSAs fire every 10 years) to a high of 7. More typically, however, the range was from two to three WFSAs fires per year. Again, informants noted the high level of variability in WFSAs fires. Indeed, in many of the land management units contacted in the course of the study, WFSAs fires had not occurred for 2 to 3 years. One informant, who had been in the same Ranger District for more than 20 years, noted that a WFSAs fire had not occurred in his district until 1994, and that only two project fires had occurred in the district in 20 years. Although other land management units had experienced more frequent WFSAs fires, it appears that the frequency of fires requiring that a WFSAs be conducted is typically very low (often less than one per year on average) at the National Forest level, and there are many years in which there are no WFSAs fires. Concomitantly, at the Ranger District level the frequency is even less. Thus, for many land management units, line officers (particularly at the District level) may encounter the need to conduct a WFSAs on a less-than yearly basis and frequently only once or twice over a 5- (or more) year period. Currently, fire reports (Form FS 5100-29) submitted to the National Interagency Fire Management Integrated Database (NIFMID) do not include an indication of whether a WFSAs was performed for a fire incident. Thus, estimates of WFSAs frequency for a given land management unit can only be obtained locally.

Perceived Value and Utility of the WFSAs Process

A major determinant of the quality with which a decision making process is implemented is the perceived value of the process by those who use it. The interviews and follow-up survey included four items that asked informants to indicate their perception of value or usefulness of the WFSAs process. These

Table 1-Perceived value of WFSA as a decision making.

In you experience, how useful have you found WFSA as a decision making tool in fire management?	Percentages
Not useful	0.0
Slightly useful	9.3
Somewhat useful	55.6
Very useful	35.2
In your experience does WFSA generally lead to the best fire suppression strategy?	
Rarely	0.0
Sometimes	46.3
Most of the time	51.9
Always	1.9

included usefulness of WFSA as a decision making tool; the ability of WFSA to identify the best fire suppression strategy; the ability of WFSA to consider land management objectives and final outcomes of a wildfire action; and the ability of WFSA to control large-fire suppression costs.

Two questions asked informants about the general utility of WFSA, including whether it leads to the best fire management strategy (*table 1*). A large majority of the informants indicated that they found the WFSA process to be "somewhat" or "very" useful as a decision making tool in fire management, although only about one-third found it very useful. None of the informants indicated that they found it not at all useful.

The intended purpose of the WFSA process is to aid in the selection of the best fire management strategy for dealing with an escaped or wildfire incident. However, when asked whether WFSA generally leads to the selection of the best fire management strategy, only slightly more than half indicated that it does so "always or most of the time." Although none of the informants indicated that it rarely leads to the best strategy, a sizable portion indicated that it "sometimes" leads to the best strategy. In general, informants were positive about the usefulness of WFSA as a decision making tool, but slightly less so about its ability to aid strategy selection.

The general perception of the usefulness of WFSA was unrelated to its perceived ability to lead to the best fire management strategy ($\chi^2 = 3.78$; $df = 4$; $p > 0.20$), suggesting that the perceived value of the WFSA process very likely includes factors not specifically identified in the WFSA policy. Indeed, the interviews revealed that the WFSA process has dimensions of value that go beyond its usefulness as a decision making aid or tool. For example, one senior fire management officer (FMO) stated "[The WFSA] forces you to sit down and think about what you're doing... it makes you be consistent." Another resource staff officer noted "[WFSA] provides a mechanism to manage from... [it] provides a focus.... We have to make some forecasts, work with other agencies, and estimate some things." The communication value of the WFSA was frequently mentioned, in comments such as "WFSA draws management into the decision making process... [it's] a good communication tool"; or, "[WFSA] is a communication tool between the agency administrator and the incident management team."

Value of WFSA in Considering Outcomes and Controlling Wildfire Costs

Although the WFSA process is intended to assist decision making in selecting a fire management strategy, the process also includes a careful consideration of land management objectives and the impact of fire on those objectives. Thus, a successful WFSA is, in part, one that selects a fire management strategy that is

Table 2—Perceived value of WFSa in meeting land management objectives and controlling suppression costs.

How well does WFSa consider land management objectives and final outcomes of the wildfire action?	Percentages
Not well	7.7
Slightly	21.2
Moderately	65.4
Very well	5.8
With regard to the costs of large-fire suppression, how much do you think the WFSa process, if done properly, can help control such costs?	
Not at all	0.0
Very small amount	22.2
Some control	46.3
Substantial control	31.5

consistent with land management objectives and that achieves suppression outcomes consistent with land management plans. In addition, the WFSa policy identifies cost of suppression efforts as a criteria against which alternative strategies should be compared. Given the escalating costs of suppressing wildfires, a reasonable question to ask of WFSa is the degree to which it can, if appropriately applied, help control such costs. Responses to two probes related to these issues were analyzed (*table 2*).

With regard to consideration of land management objectives and final outcomes of fire suppression actions, the majority of informants indicated that the WFSa does this "moderately" well. Very few informants indicated that WFSa accomplished this objective "very well" or "not well." A modest relationship existed between perceived usefulness of WFSa and its perceived ability to consider fire suppression outcomes in light of land management objectives; those who judged WFSa better at considering outcomes also tended to view WFSa as more useful ($\chi^2 = 12.22$; $df = 6$; $p < 0.06$). A much stronger relationship existed between WFSa's ability to select the best fire management strategy and its consideration of outcomes; those who tended to judge WFSa as better at considering outcomes were also more likely to see WFSa as leading to the best fire management strategy ($\chi^2 = 15.23$; $df = 6$; $p < 0.01$). It appears from these results that the perceived quality of WFSa as a decision making process is related, at least in part, to judgments about its ability to consider outcomes of fire suppression actions in light of land management objectives.

A critical concern in fire management is control of suppression costs. Informants were asked to indicate how much control the WFSa process can have over large-fire suppression costs, assuming the WFSa process was done properly (*table 2*). A wide range of responses to this question was exhibited; with 31.5 percent indicating "substantial control" was possible, while another 46.3 percent indicated only "some control" was possible. At the extreme, 22.2 percent indicated only a "very small amount" of control was possible.

Judgments about the ability of WFSa to control wildfire suppression costs were not related to either general perceptions about the usefulness of WFSa as a decision making tool ($\chi^2 = 4.18$; $df = 4$; $p > 0.20$), or to judgments about WFSa's ability to lead to the best suppression strategy ($\chi^2 = 2.56$; $df = 4$; $p > 0.20$).

In the interviews, informants exhibited similar variation in discussing the potential of the WFSa to control suppression costs. Indeed, of the many topics discussed in the course of the interviews, the issue of fire suppression cost control was one of the most volatile and evocative of differing opinions and views. Some informants indicated that some of the factors responsible for suppression costs, particularly social and political factors, cannot be sufficiently accounted for in the WFSa to permit their control.

Table 3-Responses to items assessing quality of information for WFSA.

Are natural resource values typically available in a form that can be used directly in an WFSA?	Percentages
Not available	1.9
Seldom available	60.4
Sometimes available	24.5
Usually available	13.2
Typically, how usable are land management plans for the needs of WFSA?	
Not usable	5.7
Slightly usable	32.1
Somewhat usable	45.3
Very usable	17.0

Availability of Information for the WFSA

The WFSA process requires a number of types of information, including natural resource management objectives and natural resource values, much of which comes from the land management planning process. The availability and usability of this information for the WFSA process was assessed by two questions (*table 3*).

Availability of Natural Resource Values for WFSA

Few of the informants indicated that natural resource values are "usually available" in a form that can be used directly in a WFSA (*table 3*), while the majority indicated that resource values are "seldom" available. Availability of natural resource values was weakly related to perceived usefulness of WFSA as a decision-making tool ($\chi^2 = 8.68$; $df = 6$; $p < 0.20$) and was unrelated to judgments about the ability of WFSA to select the best fire management strategy ($\chi^2 = 2.12$; $df = 6$; $p > 0.20$), suggesting that resource values are perceived as marginally important in aiding actual fire management decision making. This does not mean, however, that improvements in the availability of natural resource values are not or would not be viewed positively.

Informants typically indicated that timber values for their Forest were available and usable in the WFSA. However, other categories of natural resource values typically were not, such as for fish, recreation, air, and water. As one informant put it, "the toughest part (of the WFSA) is struggling with the resource values." Although not all informants would agree that this is the most difficult aspect of WFSA, most comments echoed those of one informant who noted that "obtaining good resource values has always been a problem."

Although some of the difficulties with resource values center around their availability, others may be more related to their meaningfulness and conceptual validity in fire management decision making. In commenting on the logic of WFSA, one informant noted that the "economic model is too narrow.... [We] can't trade off property." Informants also questioned the meaningfulness of attaching economic values to natural resources that have no commodity value. For example, one informant commented that "as far as resource values go, it's more the qualitative than the quantitative." Some of the objections to quantitative resource values may stem from a lack of understanding or awareness of how such values are obtained. Other objections can arise when natural resource values are inconsistent, or when the way in which they are consistent is not obvious. For example, one informant expressed his experience with quantitative natural resource values by asking: "Why is sagebrush valued at \$5.00 an acre in Burns (Oregon) and \$150 an acre in Winnemucca (Nevada)?"

For the most part, informants indicated that the only way they could incorporate non-commodity resource values into the WFSA was through their specification as evaluation criteria or as critical natural resource concerns. However, quantifying these values directly as a basis for calculation of a total

dollar value for damage to the natural resource base associated with each fire management strategy specified in the analysis was generally seen as not feasible given the current availability and usability of such values.

Usability of Land Management Plans by WFS

With regard to the usability of land management plans in the WFS process, about one-third of the informants indicated that land management plans are "slightly usable" for the needs of WFS, while nearly half indicated that they are "somewhat usable" (table 3). There was no significant relationship between usability of land management plans and the value of WFS as a decision making tool ($\chi^2 = 6.52$; $df = 6$; $p > 0.20$). However, a very strong relationship did exist between usability of land management plans and the judged ability of WFS to lead to the best fire management strategy; those who saw land management plans as more usable by the WFS process also tended to judge WFS as leading to the best suppression strategy ($\chi^2 = 16.72$; $df = 6$; $p < 0.01$). Thus, it appears that better quality land management planning is a necessary precursor to improving fire management decision making and to improving the quality of implementation of the WFS process.

Informants in the interviews frequently indicated that a problem with land management plans is their lack of a specific role for fire in the context of land management objectives in management areas that do not include wilderness. Some informants also noted that the economic costs associated with fire suppression are not adequately considered as part of the overall costs of land management and that the total costs of land management (including fire suppression costs) might be reduced by allowing fire to achieve resource management objectives.

Other informants noted that land management plans have not been updated in as much as nearly a decade and that in that time views about the role and value of fire in forest ecosystems have changed. However, land management plans have yet to incorporate these changes. As one informant noted regarding the usability of land management plans for WFS, "Land management plans and fire management plans don't reflect changes (over time) in natural resource values." Other informants made similar comments, noting that the land management planning process does not keep pace with changes in the resource base and resource values.

However, in other land management situations, the usability of the land management plan for WFS may be limited by the range of options for dealing with fire. As one informant from a southern California fire forest with high fire loading and complex urban interface problems commented, "Our land management plan calls for full suppression ... [We have] a very limited decision space." Thus, the usability of the land management plan by WFS may (under some circumstances) be severely constrained by characteristics of the land management unit that limit the number and/or type of strategic options for dealing with fire. As a second informant in a similar type of forest with a complex urban wildland interface commented, "[We] already know what to do - full control. We have only one option."

Assessment of Probabilities of Success or Failure

A key assessment in the WFS process is the assignment of probability of success/failure to each alternative suppression strategy included in the analysis. Of all the judgments required in the WFS, probability assessments appears from the interviews to be the most difficult. As one informant expressed it: "The weakest thing [in the WFS] is going to be the probabilities." Informants tended to indicate that lack of fire experience leads to inadequate consideration of the national or regional availability of suppression resources and, therefore, to overly optimistic assessments of the likelihood that a given suppression strategy will accomplish its objectives (e.g., containment size, containment time, suppression costs).

In the survey, informants were asked to judge the level of precision with which probability assessments of success /failure can be made. Very few informants (3.8 percent) thought that probabilities could be assessed with high precision (i.e., ± 5 percent). A slightly higher percentage (9.6 percent) thought that probabilities could only be assessed with a precision of ± 40 percent or more. The vast majority of informants thought probabilities could be assessed with moderate to limited, precision (i.e., ± 15 percent to ± 30 percent).

Perceived Causes of Poor Quality WFSA's

Informants were asked to judge how often each of a number of factors were attributable as causes of poor quality WFSA's. Essentially, these probes assessed the experiences informants had with poor WFSA's and their views on the factors that contribute to them.

The highest rated causes of poor WFSA's were related to inadequacies in WFSA training and experience: over 74 percent of respondents indicated that poor WFSA's are "often" or "almost always" caused by lack of adequate WFSA training on the part of the line officer responsible for the WFSA. Nearly the same percentage (75.4 percent) indicated that poor WFSA's are "often" or "almost always" caused by lack of line officer WFSA experience.

Additional problems associated with implementing the WFSA process were related to the availability of fire management experience and WFSA expertise as well as the availability of time to conduct the WFSA. Regarding time availability, about 60 percent of the informants indicated that insufficient time to do the WFSA properly was "often" or "almost always" a cause of poor WFSA's. In addition, 20.4 percent of the respondents indicated that lack of fire management experience is "almost always" a cause of poor WFSA's, while 38.9 percent indicated it is "often" a cause.

Perceived Improvements to the WFSA Process

As part of conducting the interviews, informants were encouraged to offer suggestions or ideas for improving the implementation of the WFSA process. A number of suggestions most commonly mentioned were included in the follow-up survey, along with others that are currently being implemented in some Regions or Forests. Informants were asked to evaluate, based on their experience, how much improvement in WFSA would result from each one (*table 4*). A four-category response scale was provided: no, slight, moderate or large improvement. The categories "no" and "slight" are collapsed into a single category, as are the categories "moderate" and "large."

The single measure viewed as yielding the greatest improvement in the WFSA process was "better natural resource values": over 85 percent of the follow-up survey respondents indicated that this would lead to a "moderate or large" improvement in the WFSA. Such an overwhelming endorsement of better natural resource values appears somewhat inconsistent with informants views regarding the need for economic analysis in the initial WFSA. Indeed, the interviews generally revealed that the economic analysis portion of the WFSA is not the part of the WFSA that figures into judgments of the WFSA's overall quality. The explanation for this apparent inconsistency lies in understanding the difficulty of the informants to deal with the economic analysis portion of the WFSA. Virtually all of the informants noted that they perceive the WFSA process to acquire greater importance than in the past and that fire management decisions today require stronger economic justification. Although the WFSA has always had an economic analysis, this aspect of the WFSA has been dealt with historically by using subjective ratings. Greater emphasis on the WFSA process signals the need for a more complete documentation and specificity in its components. Given the very limited availability and usability of natural resource values at present, much improvement is impossible.

Table 4-Responses to the follow-up survey probe: "Listed below are a number of possible changes to WFSa. In your opinion, and based on your experience, how much improvement in WFSa would result from each one?"

Potential WFSa Improvements	No/slight improvement	Moderate/large improvement
	Percentages	
Better natural resource values	13.2	86.8
Better training in how to analyze alternative fire suppression strategies	25.9	74.1
Better definition of the role of fire in land management plans	25.9	74.1
More fire management experience for line officers	20.4	79.6
Better methods for estimating suppression costs	35.2	64.8
Preplanning of WFSa's based on, for example, management areas in forest plans	30.2	69.8
A computerized version of the WFSa	30.7	69.3

Informants were also genuinely concerned about doing a good job of conducting the WFSa and, as many informants put it, "preparing a quality document." A number of the informants who had been incident team commanders noted that the overall neatness and thoroughness of the WFSa document itself contributed to their confidence in the local agency administrator and signaled to them the administrator's awareness and understanding of their own natural resource management objectives. From this perspective, better natural resource values in the WFSa provide an improvement in the overall implementation of the process, although these may not be a critical element of an initial WFSa.

Almost equally high percentages of respondents indicated a moderate or large improvement in WFSa's would result from better training in how to analyze alternative fire suppression strategies (74.1 percent); better definition of the role of fire in land management plans (74.1 percent); and, more fire management experience for line officers (79.6 percent).

Informants were also positive about changes to some of the procedural aspects of the WFSa. More than half (69.8 percent) indicated that preplanning of WFSa's would improve their quality. A high percentage (64.8 percent) indicated that better methods for estimating suppression costs would also improve WFSa's.

Conclusions

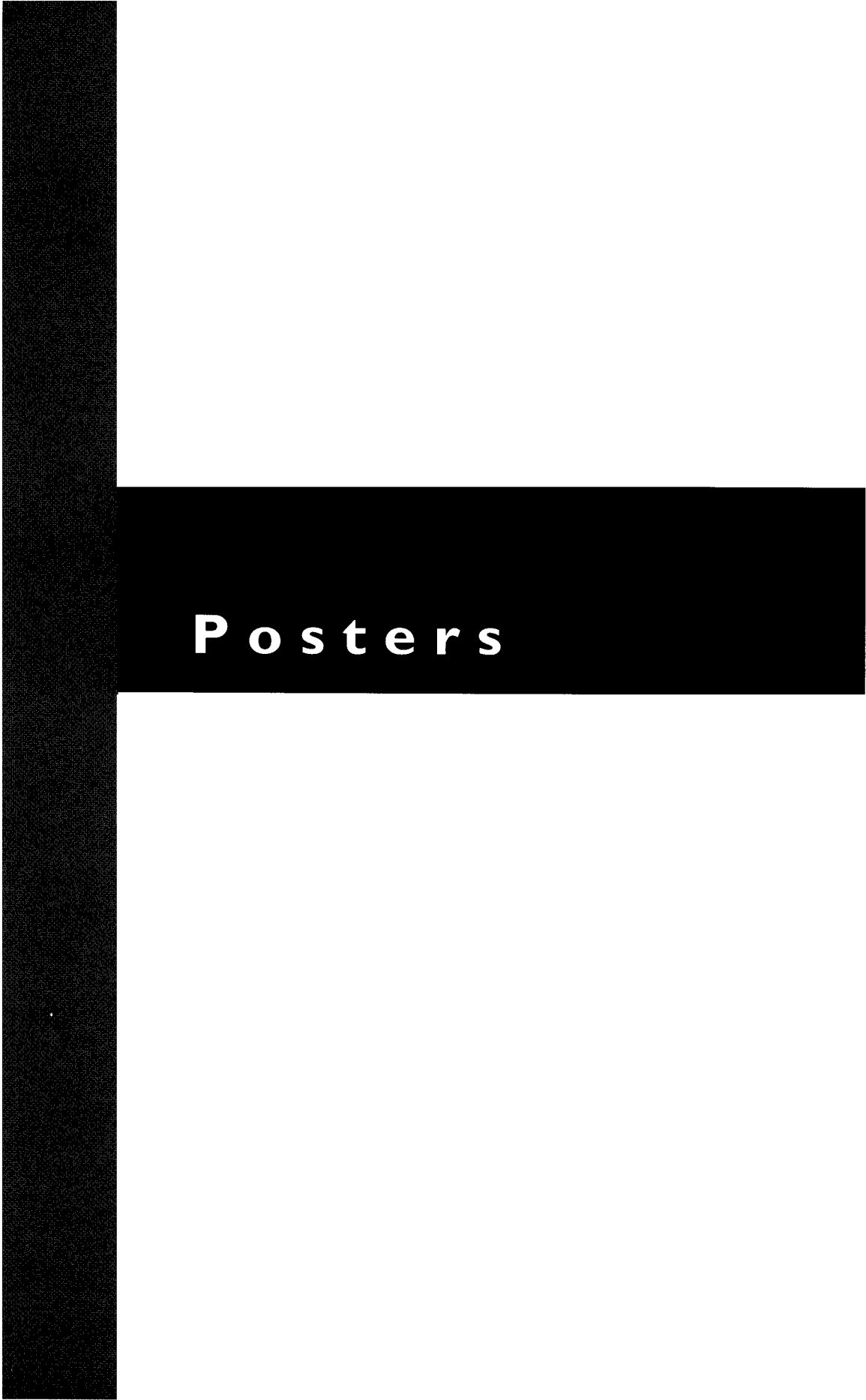
The WFSa procedure is one of the more intensive decision making processes implemented in U.S. Federal fire management. The experiences of senior fire and natural resource management personnel reported in this study suggest that though the process is a valued one, a number of factors potentially compromise the quality of its implementation. The frequency of WFSa fires is relatively low, thereby requiring the process to be undertaken somewhat rarely, perhaps less than once per year in some Forests or Ranger Districts. Although the WFSa is a conceptually sound procedure, based on principles from the decision sciences, the complexity of the process coupled with the highly stressed circumstances under which it must be conducted can lead to poorly done WFSa's. Lack of training in WFSa, limited availability of relevant WFSa and fire management expertise, a limited time-frame within which to conduct the analysis, lack of

connectivity between land management planning and the WFSA, and lack of usable natural resource values are some of the factors that interact to degrade WFSA's done on fire incidents.

It appears from the experiences and perceptions of senior fire and natural resource managers that the WFSA process would be improved if more training was provided in WFSA and if the WFSA process was integrated more closely with the land management planning process. In some forests, pre-planning of WFSA has already begun and is facilitated by the implementation of the WFSA process on a PC-computer platform. We foresee that this extension and refinement of WFSA will provide an opportunity for WFSA to become a high-quality decision support tool in both fire incident and land management decision making.

Acknowledgments

This study was a cooperative project by MacGregor-Bates, Inc. under Research Joint Venture Agreement #PSW-97-004-RJVA with the USDA Forest Service. We thank the dedicated fire management professionals who participated in this study. Their cooperation and dedication to improving fire and natural resource management made this effort possible.



P o s t e r s

Valuing Forest Fire Damage to the Environment¹

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Abstract

Forest fire damage to the environment must be re-evaluated. On the one hand, negative impacts of small forest fires on the environment are negligible, requiring little attention. On the other hand, large fire damages and losses are much greater than those accounted for from losses of goods and services with market values alone. Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC) has developed a model that accounts for all factors that increase the productive, recreational, and ecological value of ecosystems, from a societal point of view, for all locations on the territory. The forest fire protection plans for an area can evaluate its economic efficiency by using a forest fire simulator to compare the total value of the area burn under the plan's recommended measures, and what it would burned without the plan.

Investments in the environment have always been harmed in conventional economic analysis by the fact that a large part of the goods the environment produces have no market price. This situation is particularly striking in Spain because of the enormous reduction in the public deficit pursued by the country in recent years in order to adapt the economy to the standards of the group of countries that have adopted the Euro currency as their common currency.

As an engineering company, Tecnologías y Servicios Agrarios, S.A. (TRAGSATEC) has designed general action plans against forest fires in various regions of Spain (competence for environmental matters has been assigned to the regional authorities). In this context, a methodology has been developed that allows financial justification of the budget for the actions envisaged in the proposed plan. The valuation data presented in this paper come from the model's application to the Madrid region.

The methodology is based on two computer models developed on a geographic information system (GIS): an integrated economic valuation (IEV) model for forest systems and a forest fire behavior simulator (FFS). Both models comply with technical specifications. They give individualized estimates for each forest hectare of the region. In addition to the specific plant cover of each 1-hectare cell, the models include the parameters defined by the cell's situation (slope, distance from population centers, etc.). Given that the main objective of the models is the valuation of forest fire areas, it will be assured that the areas with major fires (500 hectares or 1,200 acres) are significant at the model scale.

The IEV estimates the value of the forest systems, including all aspects of their value. Specifically, a valuation is given for priced goods (e.g., the wood), unpriced goods with a use value (e.g., recreation), and non-use goods (e.g., their existence *per se*).

The valuation is made by making an estimate of the annual income generated by the forest ecosystem and calculating the present value of the infinite stream of cash flows equal to the calculated income. It is assumed that the forest ecosystem will remain in its current state; intergenerational justice can thus be guaranteed, even with results obtained by applying different discount techniques with positive rates.

The capitalization of the annual income from all goods produced by the forest ecosystem is done by using a social time preference rate (STPR) discount rate. The rate used in the model's application to the Madrid region was 2 percent.

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, California.

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Technical specifications of the FFS include its use of BEHAVE equations to parameterize the fires behavior. It can generate a tessellation tile for each fire perimeter corresponding to the time intervals defined. It also allows automatic loading of the conditions of the fires to be simulated (for example, weather conditions and coordinates of the origin of all fires that occurred during the last decade).

Proposed Methodology

Integrated Economic Valuation (IEV) Model for Forest Systems

For valuation purposes, the goods produced by forest ecosystems are classified in three aspects: productive, recreational, and environmental.

Productive Aspect

This category groups the income of all priced products generated by the forest ecosystem (private goods): wood, timber, fruit, grazing land, hunting, cork, seeds, etc.

The process begins by estimating the annual income generated by the cell for each element in the model. This is done by estimating the production of the element in the cell and valuing said output at its unharvested market price. If the forest ecosystem is immature, a financial adjustment is made between its age and the rotation (date on which exploitation begins). Lastly, if the element is of sufficient economic importance, the cells are reclassified (the income for the territory as a whole remains unchanged) according to the territorial parameters of each one of the cells capable of influencing the income of the element. In the case of wood, these parameters would be slope and accessibility, for example.

Recreational Aspect

This category reflects the value of forest ecosystems as leisure areas. Each one of the recreational areas is valued using the Travel Cost Method. The model requires valuation of all recreational areas of the region. Some are very small and have no visitors data. These are valued by estimating visits as a function of the variables that define the attractiveness of the recreational area: landscape of the surrounding zone, type of water-related activity pursued in the areas, and type of plant cover.

The landscape is valued with the hedonic prices method, as it already forms part of the pricing function of the homes in towns surrounding the city. The other two explanatory variables are the distance to the capital and the population density of the town in which the home is located.

Environmental Aspect

This aspect covers public goods with no use. It includes option, donation, legacy and existence values and is valued using the contingent valuation method. Some 1,122 valid questionnaires were completed by citizens age 16 or more residing in the region with a single dichotomous question on their willingness-to-pay (WTP) to assure the survival of the region's forest systems. The resulting WTP was \$38 per citizen per year.

In order to obtain the environmental value in a cartographic format, the overall results of the contingent valuation must be incorporated into each of the 1-hectare cells defined in the region. This was done by consulting a panel of experts on the parameters that determine the environmental quality of a point in the form of a quantitative index. The overall WTP was then distributed proportionally to the value of the index at each point of the area.

Aggregate Economic Value

The total economic value is determined in each cell by merely adding up the three aspects considered. Before adding up the three aspects, an adjustment

must be made for elements that could be counted twice. For example, citizens may internalize in their WTP the recreational use they make of the forest ecosystems, and there are obvious incompatibilities between some of the priced elements. The first duplication is avoided by adding a question in the questionnaire regarding the respondent's recreational use of the ecosystems and analyzing the response in the two subsamples. The second duplication is avoided by inclusion in the model of a matrix of incompatibility coefficients that discounts double use.

This coverage grid is the final result of the model and allows the integrated value of any tract of significant size to be automatically determined.

Forest Fire Behavior Simulator (FFS)

The General Plan (GP) for Defense against Forest Fires

The GP is the source of the data that determine fire behavior in the region's ecosystems. The fire's reaction is established by studying the risk (frequency and causality), weather, flammability, combustibility, and slope of the terrain.

The result of the planning process is a set of proposed actions for prevention, control, and extinguishment. These actions have a financial cost for society that needs to be justified.

FFS Inputs

The elements that define a fire's reaction to ecosystems are incorporated in the simulator in different forms:

- Basic coverages---The slope of the terrain is input into the FFS with a digital elevation model (DEM) and its combustibility by transforming the different types of vegetation into fuel models.
- Fire parameters to be simulated---The frequency is input by means of the coordinates of a historical series of fires that occurred during the previous decade, and meteorology is accounted for by inputting the wind speed and direction existing in each of the historical fires. This information is obtained from the fire reports.

FFS Outputs

The surveillance and extinguishment actions included in the GP involve shortening the time needed for bringing the fire under control, and the prevention actions involve the greater improbability of a fire's advance (barriers, etc.), which may be expressed as a smaller blaze area for a given duration of the fire.

The collection of historical fires may be simulated two times: once with the basic conditions and control times that actually took place and another with the proposals formulated in the GP and the target control times.

The result is a difference in the burned land area (smaller on average), which is taken as the land area saved by the GP and capable of valuation by using the IEV.

Results of the FFS

The land area saved each year was estimated (*table 1*). The base 10-year historical series of fires was applied to the two situations studied: the territory without the actions proposed in the GP and with the historical control times and the territory with implementation of the proposals and the target control times (*table 1*). The average land area in each year for these two situations is totalled for the number of fires that occurred, and the saved area is obtained as the difference between the totals for both situations.

Table 1-Forest fire behavior simulator (FFS) results: annual saved surface estimation.

Year of GP	Number of fires	Without general plan		With general plan		Total saved surface
		Total average surface	Total surface	Total average surface	Total surface	
-----ha-----						
1	69	5	341	3	218	122
2	116	3	404	2	233	170
3	140	70	9,780	65	9,168	612
4	148	17	2,557	16	2,397	161
5	295	3	985	2	655	330
6	398	3	1,071	2	622	449
7	77	8	621	5	379	242
8	129	16	2,039	13	1,726	313
9	102	19	1,934	17	1,744	190
10	302	3	806	2	530	276
Total / Average	1,776	11.56	20,539	9.95	17,673	2,865

Table 2-General Plan (GP) results: cash flow and financial ratios.

Year of GP	Total saved surface	Surface average value	Saved surface value	GP cost	Profit / -Loss
-----ha-----					
-----\$/ha-----					
1	122	12,081	1,473,882	4,674,306	-954,217
2	170	10,993	1,868,810	3,870,646	-150,557
3	612	12,799	7,832,988	920,109	2,799,980
4	161	18,790	3,025,190	833,735	2,886,354
5	330	10,845	3,578,850	768,954	2,951,135
6	449	10,749	4,826,301	617,800	3,102,289
7	242	14,707	3,559,094	1,481,540	2,238,549
8	313	11,655	3,648,015	401,865	3,318,224
9	190	18,886	3,588,340	509,832	3,210,257
10	276	13,766	3,799,416	809,070	2,911,019
Annual average	287	12,985	37,200,886	14,887,857	22,313,033

The first implicit assumption is that the number of fires depends on socio-economic conditions and not on the GP actions and, therefore, will remain constant for as long as the conditions remain constant (citizen awareness initiatives may improve the situation but not to a significant degree in the short term). The second assumption is that without the GP actions, fire control effectiveness would be the same as in the past, unlike the effectiveness that will be achieved with the GP, which is taken as the GP target levels.

Results of the GP Cash Flow and Financial Indicators

To value the area difference of the two situations simulated for all fires of the historical series, the total saved area and average value per hectare were determined by using the IEV method (*table 2*).

The average values per non-forested hectare saved are \$10,501/ha and \$23,919/ha per forested hectare. In the region of Madrid, the value of an ecosystem is distributed in the following proportions: productive value, 10 percent; recreational value, 15 percent; and ecological value, 75 percent.

The total value of the saved area is calculated by simply multiplying the average value per hectare by the number of hectares saved. The result gives the

profit generated by the GP but not necessarily with the time sequence expressed by the historical series. For this reason, each annual period is assigned the average gain for the period during which the GP is in force.

The GP costs are taken as the aggregate budget for the proposed incremental actions. They are concentrated in the initial years of the GP because they primarily consist of forestry and infrastructure work (broad-leaf re-population, barriers, improvements to access ways, increase in water points, etc.). In this case the projected sequence in which the actions are to be undertaken is of bearing for the GP cash flow.

The difference between the stream of value saved from fire and of the costs necessary for generating those savings gives the GP cash flow, which may be analyzed using financial ratios.

Conclusions

The proportions in which the different aspects contribute to the aggregate economic value of the forest systems of the region of Madrid may be considered atypical, reflecting the peri-urban location of the forest ecosystems in this large metropolitan capital of Spain.

The plans for protecting the forest ecosystems against fire may be financially justified (positive net present value [NPV], high profitability and internal rate return [IRR], and short pay-back) if we consider all goods produced by the systems, irrespective of whether or not they have a price. If only priced goods are considered, however, the high costs of protection do not appear justified.

Financial ratios	Value
NPV 2 percent	\$19,507,598
Profitability 2 percent	239.25 percent
IRR	124.18 percent
Payback 2 percent	2.41 years

The forest fire simulation models, used in combination with the geographical models for integrated valuation of forest systems, allow the effectiveness of the GPs to be determined, simulating a representative collection of the fires in the zone in pre-GP and post-GP conditions and valuing the different land areas affected by fire.

Defense System against Forest Fires in the Andalusian Region in Spain¹

Ernesto Fernández de la Fuente²

Abstract

In response to the harsh climate conditions of the Mediterranean region in the Andalusian region of Spain, Andalusia developed a new model of defense against forest fires in 1993. The system, known as the Andalusia Community Forest Fire Plan (INFOCA), was organized through forest defense centers at the provincial, regional, and local levels. The new organization required a significant increase in financial and fire fighting resources.

Location and Characterization of the Area

Spain is located in southwestern Europe and forms the western coast of the Mediterranean Sea. Andalusia is located in southern Spain and the region contains both forest areas and plan protected areas (natural parks and similar).

The population of Andalusia is 7,216,649, with 53.4 percent urban inhabitants and 46.6 percent rural inhabitants. Within an area of 87,000 km², 47 percent is agricultural land, 3.5 percent has other uses, and 49.5 percent is classified as forest areas. Of the total forest area, 10.31 percent is densely wooded, 52.78 percent is pasture land and sparsely wooded scrubland, and 36.91 percent is treeless.

Precedents

The region of Andalusia is a clear example of the harsh climate of the countries in the Mediterranean region, which has given rise to a climactic model of high summer temperatures, a big drop in relative humidity, and drying winds. The orography of the area has slopes that reach 3,480 m in only 34 km, which is a serious problem that can cause forest fires to spread rapidly. Fires affect vegetation, fauna, and the loss of land by erosion.

The current model of defense against forest fires in Andalusia originated in 1993. The model changed in that year as a result of analysis by all the stakeholders, including forest administration, private landowners, agrarian organizations, trade unions, and the university. The events that gave rise to the debate that led to the abandonment of the previous system were the sharp increase in the area of land burned in 1991 and the fire in the Grazalema Nature Park that caused the death of five firefighters.

Number of Fires and Area Affected

In 1993 to 1998, the Andalusia Community Forest Fire Plan (INFOCA) increased the average financial investment by 60 percent compared to the previous period (1988 to 1992), reduced by one-half the area affected by fires each year, and reduced the number of large fires.

The Forest Defense Centers, the Provincial Operations Centers, and the Regional Operations Center are all located within Andalusia. They have the following resources:

- Ground resources:
 - 234 fire lookouts
 - 263 specialized firefighter teams

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, California.

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- 155 mobile firefighter team
- 4 special back-up brigades
- 92 fire engines
- 9 mobile meteorology and transmission units
- 1 advanced forest fire tracking unit
- 4,526 total number of people in ground resources.
- Aircraft resources:
 - 21 helicopters for transport/ fire suppression
 - 5 ground loading planes
 - 2 Canadair CL215 amphibian planes
 - 3 coordination planes.

Fire Fighting Action Plan

Andalusia has the following technical resources for management and coordination:

- Centers:
 - Regional Operating Center
 - Provincial Operating Center
 - Local Forest Defense Center.
- Prevention and planning:
 - Thematic mapping
 - Risk indexes
 - High priority action plans against forest fires
 - Preventive silviculture improvement in infrastructures
 - Routes into the forest
 - Water supply points
 - Helicopter pads
 - Fire lookout information and awareness-raising campaigns.
- Detection:
 - Network of fire lookouts
 - Automated detection infrared (IR) wood system
 - Mobile observation teams.
- Suppression:
 - Specialized teams transported in helicopters
 - Firefighters' jeeps
 - Mobile firefighters
 - Back-up brigades
 - Heavy machinery
 - Meteorological transmission mobile unit (UMMT) and advanced forest fire follow-up unit (UNASIF).
- Aircraft resources:
 - ACT (Air Tractor; PZL, Grumman)

- Helicopters for transport/ fire suppression (Bell 205 and 206)
- Canadair CL215
- Planes for coordination and display of aerial photography.
- Follow-up activities:
 - Investigation into causes
 - Beginning legal action (autonomous police)
 - Damage assessment
 - Plans to aid the natural regeneration of vegetation
 - Reforestation.

This action plan is backed up by public collaboration in a two-pronged system of detection, via a free telephone line for emergency warnings, and of fire suppression, through the Local Rapid Assistance Groups (volunteers).

In the constant struggle against forest fires, new technology and materials are appearing. Although this is not the definitive solution, new technology has been a very useful tool in helping with some of the difficulties involved in fighting against forest fires. Some of the new technology includes:

- Bacares, the specialized system for geographic information.
- System for the display of real time images of forest fires.
- An automated infrared surveillance and detection system for forest fires (Bosque System).
- A digital model of land-simulation of fire behavior (ARC/ INFO CARDIN).
- Network of automatic weather stations.
- Remote sensing of forest fires.
- FORMA-2, a program of in-service training for workers.
- Integrated crisis management systems for large fires.
- Introduction of quality and environmental management systems.

International Cooperation

The Andalusian regional government has developed cooperation programs with the Kingdom of Morocco and the Eastern Republic of Uruguay. The cooperation program includes:

- Drawing up the fire management plan in the Rif region of northern Morocco.
- Building and opening the Center for Training in the Defense against Forest Fires, The Forest Reserve of Cape Polonio, and the Aguas Dulces (region of Rocha).

The Impacts of Forest Fires on Wilderness Recreation in Eastern Manitoba, Canada¹

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Abstract

This study examines the role of historic fire in the choice of recreational canoe routes in forests located in the Canadian Shield. Forests burned 10 years previous to the year we observed route choices resulted in dis-utilities to the recreationists. Forests that burned over 64 years provided significant positive utility. This information was used to develop an intertemporal amenity function which was combined with timber growth and fire risks in a Faustmann optimal rotation framework. The resulting model suggests that harvesting should be delayed in areas with significant recreational canoeing benefits.

The Precambrian Shield of Canada provides some of the finest wilderness recreation opportunities in North America in the form of lakes and rivers surrounded by forests. Forests of this region are subject to periods of natural disturbance caused by fires. Nopiming Provincial Park, Manitoba is located within the Shield. The park is a 1,440 km² area located about 150 km east of Winnipeg, a city of about 550,000 people. Much of the park is forested with jack pine (*Pinus banksiana*). However, black spruce (*Picea mariana*), white spruce (*Picea glauca*) and trembling aspen (*Populus tremuloides*) stands are also found there. The park was subjected to severe fires during 1983 (fig. 1) and hosts a limited harvest of timber that is used in a pulp mill nearby.

This poster presents results of our study on the role of burned forests on recreation site choice of canoeists. During 1993 we developed a voluntary registration system for overnight canoeists, conducted field inventories of characteristics of routes, and linked routes with the provincial forest inventory by using a geographical information system (GIS). The final data set involved trip information from 388 visitors to 20 different canoe routes.

Significance of Fire on Canoe Route Choice

Random utility models were used to estimate impacts of the 1983 burned areas on canoe route choice in 1993. Canoeists were assumed to choose routes that provide them with the largest utility or benefit (Boxall and others 1996). The model estimates the probabilities of choosing each of the 20 routes as a function of the characteristics of the routes and travel costs. We found that the presence of 1983 burns along canoe routes had a negative effect on choice (table 1), and that canoeists preferred older jack pine stands to mature black spruce or aspen stands.

Valuing Old Burns

Simulations were conducted where the areas burned in two fires in 1983 were returned to mature forest. An issue to consider with this method is the type of forest present before the fires; two simulations were used: change burned areas to original forest age, and change burned areas to mature forest. Changes in the probabilities of visiting each canoe route were calculated using each method. Since canoeists prefer to visit routes closer to their homes (all other things equal) we calculated the costs saved as a result of the simulation. We found that the 1983 fires caused a loss in the value of trips in 1993 from \$2.91 / ha to \$21.76 / ha.

¹An abbreviated version of this paper was presented at the Symposium on Fire Economics, Planning, and Policy: Bottom Lines, April 5-9, 1999, San Diego, California.

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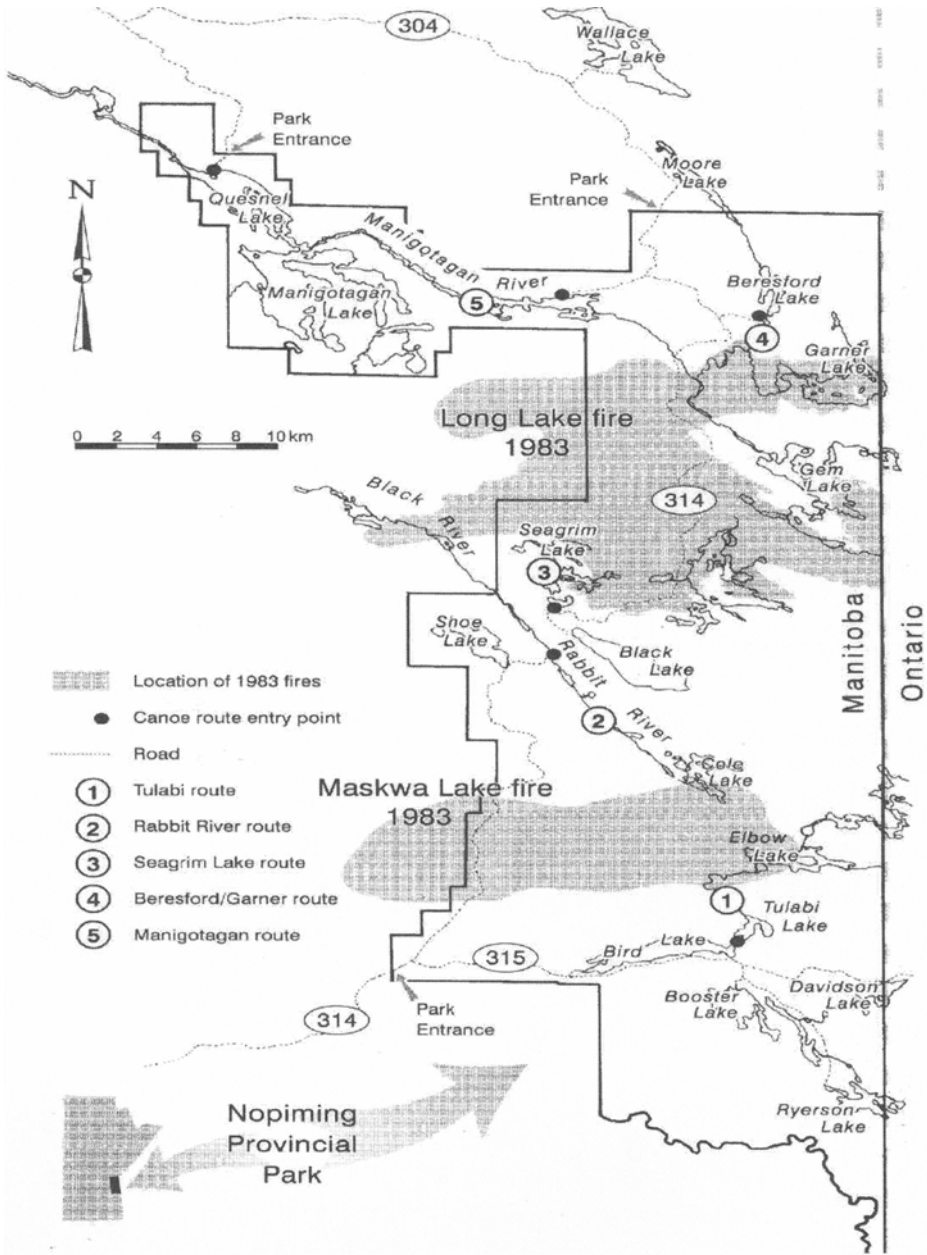
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Table 1-Effect of 1983 burns on canoe route choice and canoeist preferences.

Variable	Parameter
Travel Cost	-0.0573
Area of recent cut-blocks	0.5262
Burns 10 years or more recent	-0.1016
Area of mature Jack pine	0.6854
Area of mature black spruce	-0.9988
Area of white spruce (any age)	6.2029
Area of aspen (any age)	-3.1102
Cottages	-1.3374
Longest portage	-0.0018
Number of portages	-0.0774
Heritage river constant	3.6939
Fishing quality constant	0.7075

Figure 1
Study area: Nopiming Provincial
Park, Eastern Manitoba, Canada.



Fire and Harvest Rotation Age

Severe fires occurred in Nopiming Provincial Park in 1983. The historical fire risk in this area is 1.5 percent. With this information we attempted to include the recreation values and fires risks in examining questions regarding the timing of timber harvests.

Since burned areas from the 1983 fire provided a disamenity to recreationists 10 years after the fire, and mature jack pine stands provided a positive amenity, a function can be constructed to describe the recreation benefits of jack pine stands over time. This function is based on two points: the first an estimate of the 1983 fire damages 10 years after the fire, and the second an estimate of the benefits provided by mature forest stands 64 years after fire. Marginal values of a hectare of these two ages of stands were estimated by dividing their parameter values (*table 1*) by the travel cost parameter. Converting these values from a km² to a hectare basis yielded values of \$0.0169 and \$0.1133/ha/ trip, respectively. The 10-year-old fire (10-year-old forest in 1993) provided negative values while the mature forest (64 years or more after fire) provided positive values. Following Englin (1990) these two points were used to estimate a two-piece linear function for an individual recreationist:

$$\begin{aligned}\text{Value} &= -0.039 + 0.0019(t), \text{ in which } t < 65 \text{ years,} \\ \text{Value} &= 0.089, \text{ in which } t \geq 65 \text{ years.}\end{aligned}$$

This function (*fig. 2*) suggests fire damages are worth -\$0.039 / ha just after fire occurs and increase to \$0.00 / ha at about 17 years after fire. Stands continue to increase in value until 65 years when they reach a constant positive value for ages greater than 65 years.

Economic aspects of timber harvesting are frequently examined through optimal rotation models. The Faustmann model is the original development of this problem but only considers timber values in a deterministic framework. Hartman (1976) extended the basic Faustmann model to include amenities affected by forest harvests. An additional extension to the Faustmann model was the inclusion of fire risks formulated by Reed (1984). Reed showed that fire risks serve to shorten timber-only rotation periods since delaying harvest increases the risk of losing value due to fire. In the Nopiming case, however, multiple use of forest stands is a concern. Thus, integrating fire risk into the Hartman model is appropriate. Englin and others (1999) derive the Hartman objective function with fire risk. This function is:

$$PV(T) = \frac{(\lambda + r)}{r(e^{(\lambda+r)T} - 1)} \left[V(T) + e^{(\lambda+r)T} \int_0^T \left(\int_0^x F(z) e^{-rz} dz \right) \lambda e^{-\lambda x} dx + e^{rT} \int_0^T F(x) e^{-rx} dx - c_p e^{(r+\lambda)T} - \frac{\lambda c_b}{r+\lambda} (e^{(r+\lambda)T} - 1) \right]$$

in which $V(t)$ is the value of timber at time t , c_b is the harvesting cost, r is the discount rate, $F(x)$ is the flow of amenities (i.e., canoeing), $\int_0^T F(x) e^{-rx} dx$ is the discounted flow of amenities, λ is the Poisson parameter describing the average rate of fires, and c_p is the cost of replanting after fire or harvest. The derivation of this function involves considerable calculus which is not reported here for brevity.

The amenity function described above was used for $F(x)$ and the timber growth function was:

$$\ln(m^3/\text{ha}) = 6.1192 - 66.6471 (\text{age})^{-1}$$

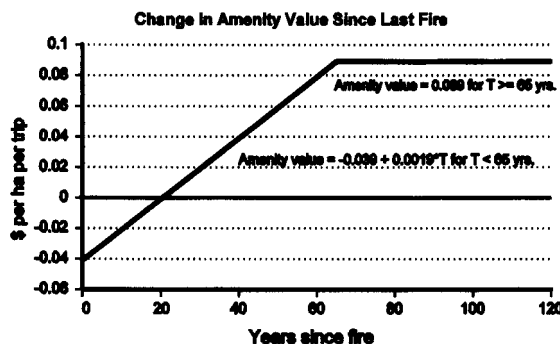


Figure 2

The recreation benefits of jack pine stands over time.

Table 2—Optimal rotation ages (yrs) for jack pine stands in Nopiming Provincial Park under different risks of fire and levels of backcountry recreational use.

Fire risk (pct)	Harvest timing ratios ¹		
	Faustman	200 users	600 users
0	35	39	51
0.5	34	37	47
1	33	36	44
1.5	31	34	42
2	30	33	40

¹Harvesting and regulating costs are assumed to be zero.

which was derived by fitting a logistic growth function to Bella's (1968) growth and yield data for jack pine in southeastern Manitoba.

The simulation involved substituting these functions into the objective function, setting the harvesting and post-fire replanting costs to zero, and calculating the value of the objective function for a series of rotation ages ranging from 0 to 150 years under a set of fire risks. The rotation age that maximized the value of the objective function is the optimal rotation age.

Accounting for risk of fire in a Faustmann framework suggests that harvesting should be done at a younger age than the Faustmann rotation (*table 2*). As fire risks increase, the optimal harvesting age decreases. This finding validates the model developed by Reed (1984). Considering a fire risk of 0 percent and implementing the Hartman rotation model suggests that harvest timing should be delayed, by as much as 10 percent if 200 recreationists are involved. When the amenity function values are included along with fire risk, our results suggest that harvesting should still be done at an older age. Thus, the amenity values tend to outweigh the risks of fire on timing of rotation. This information provides guidance to managers on spatial patterns on integrating timber values with non-timber values. However, these results are sensitive to the number of recreationists involved.

Synthesis

Fires affect recreation use patterns and values. These models can be used to establish fire protection priorities that include recreation values. For example, the Tulabi route (*fig. 1*) is currently the most valuable route in the park because of the types of forests found along its waterways. The model can also be used to examine gains (or losses) of other management policies such as new cottage subdivision developments. Integrating this information with timber values suggests that forest managers should delay harvests on those canoe routes with sizeable areas of older forests along them. In places where fire, wilderness recreation, and timber harvesting occur together, the number of recreationists may play a larger role than fire in determining harvest timing decisions.

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