United States
Department of
Agriculture

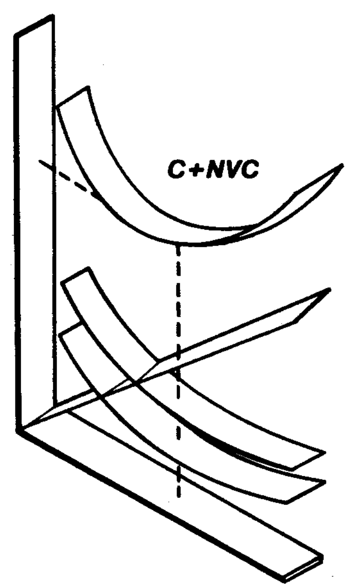
Forest Service

**Pacific Southwest
Forest and Range
Experiment Station**

General Technical
Report PSW-80

Risk in Fire Management Decisionmaking: techniques and criteria

Gail Blattenberger William F Hyde Thomas J. Mills



The Authors:

GAIL BLATTENBERGER, at the time of the study reported herein, was a senior economist with Econometric Research, Inc., Washington, D.C. She is now an assistant professor of economics, University of Utah. Her academic degrees are from Smith College--bachelor of science in mathematics/political science (1968)--and from the University of Michigan--master of arts (1972) and doctorate (1977) in economics. **WILLIAM F. HYDE** is an associate professor of resource economics, Duke University. He received bachelor of arts (1969), in international service, and master of arts (1971) degrees at American University; and master of science (1975), in natural resourcestforestry, and doctoral (1977) degrees, in natural resource economics, at the University of Michigan. **THOMAS J. MILLS,** at the time this report was prepared, was forest economist in charge of the Station's fire management planning and economics research unit. He is now group leader, Renewable Resources Economics, on the Forest Service's Forest Resources Economics Research Staff, Washington, D.C. He is a Michigan State University graduate: bachelor of science (1968), in forestry; master of science (1969) and doctorate (1972) in forest economics.

Publisher:

Pacific Southwest Forest and Range Experiment Station
P.O. Box 245, Berkeley, California 94701

October 1984

Risk in Fire Management Decisionmaking: techniques and criteria

Gail Blattenberger William F Hyde Thomas J. Mills

CONTENTS

About one-tenth of the Forest Service, U.S. Department of Agriculture's budget is allocated to fire management activities. In fiscal year 1979, the budget item for these activities totaled $216 million. Not included in this amount are the resource losses that result from wildfire. Such losses are always considerable in spite of eventual fire control (U.S. Dep. Agric., Forest Serv. 1980).

Fires are an even greater management problem than the budget figures suggest because of the difficulty of predicting their frequency, behavior, and effect on the natural resource. Factors that influence fire, such as weather and vegetation, are highly variable. Viewed in the context of decision theory, the fire management system is, therefore, pervaded by conditions of risk and uncertainty. As these terms are generally used, a *risk* exists when the potential outcomes of an action can be assigned probabilities; *uncertainty* exists when the probability of the varying outcomes cannot be determined (Knight 1933).

The data required to develop accurate probability information for the fire management system is difficult to obtain. In the past, fire managers have relied heavily on experience and intuition, leading to rules-of-thumb, such as the requirement adopted by the Forest Service in 1934 that all fires must be controlled by 10 a.m. of the second day if control is not possible during the first day. It seems likely now that decisionmaking based on analysis of risk and uncertainty inherent in a given fire management problem can increase the efficiency of fire control planning. Once risk is considered, decisions can be made in accordance with the risk preference of the planner and the public body which the planner represents. By risk *preference,* we mean willingness or unwillingness to take a risk.

Management strategies vary with attitudes toward risk, and these, in turn, vary with the scope of management responsibility. Management strategies also vary with the different components of a fire management program, from prevention and detection through fuel treatment and fire suppression activities. Finally, a manager of public lands must deal with the differences in risk and risk preferences as perceived by the manager, the fire management agency, and the public. Current rule-of-thumb strategies may be expedient in the short run and even cost-effective when decisions must be made in real time. For long-term fire program planning, however, a more constructive approach requires probabilistic analytical models, and full consideration of the risk consequences on alternative management actions.

A probabilistic fire management planning model would include all major sources of variation, from fire weather and fire occurrence through fire suppression effectiveness and resource output values. The risk embodied in a fire program option could be represented graphically and displayed in a number of ways. Whatever the approach, the risk should be explicit and should be weighted by the decisionmaker. It should not be embedded in the analytical model. For example, in the National Fire Danger Rating System, fire weather is measured only on exposed southwest slopes at 2 p.m. (Deeming and others 1977). A particular risk stance is thus determined by the measurement itself. Testing fire program performance against the 90th percentile burning index in the fourth worst year is another example (U.S. Dep. Agric., Forest Serv. 1977). Both of these measures imply a specific fire hazard which many fire control analysts believe is more severe than generally encountered.

This report examines economic theory as it is applied to fire management, describes a simulation model that includes the factor of risk, and compares fire management with other natural hazards to identify unique characteristics. Empirical data to implement the model immediately do not exist because measurement techniques and data collections are not yet adequate for that purpose. The model can suggest directions, however, for future study and identify questions that should be answered.

ECONOMIC THEORY OF FIRE MANAGEMENT

The most commonly discussed framework for economic analysis of fire management is a model that demonstrates the outcome of fire programs as their cost plus the fire-induced net value change in natural resource outputs. The fire program which minimizes "cost plus net value change" (C + NVC) is also the program which maximizes present net value (Mills 1979). Net value is appropriate here because fire effects can be beneficial as well as detrimental, as in their typical influence on wildlife habitat. The C + NVC model is a modification of one developed more than 50 years ago (Headley 1916, Sparhawk 1925). Fire suppression costs and net value changes due to fire, both beneficial and detrimental, diminish as presuppression expenditure increase (program level PL) (*fig. 1*). The C + NVC curve is the simple sum of two cost and two net value change curves. PL, is the level of presuppression expenditure at the minimum C + NVC, and therefore is the most economically efficient expenditure level.

Determining the most efficient presuppression expenditure has not always been the primary purpose of the model. Variations of it use such measures as acres (Hornby 1936), suppression force size (Arnold 1950), and fire management effort index (Simard 1976). In addition, fire control actions can be varied in the analysis. Although these actions may be broadly classed as presuppression, detection, and suppression, distinctions between the variables or fire management program components are vague and general. Regardless of how the horizontal axis is labeled, however, the model is depicted as in *figure 1*. The impact of

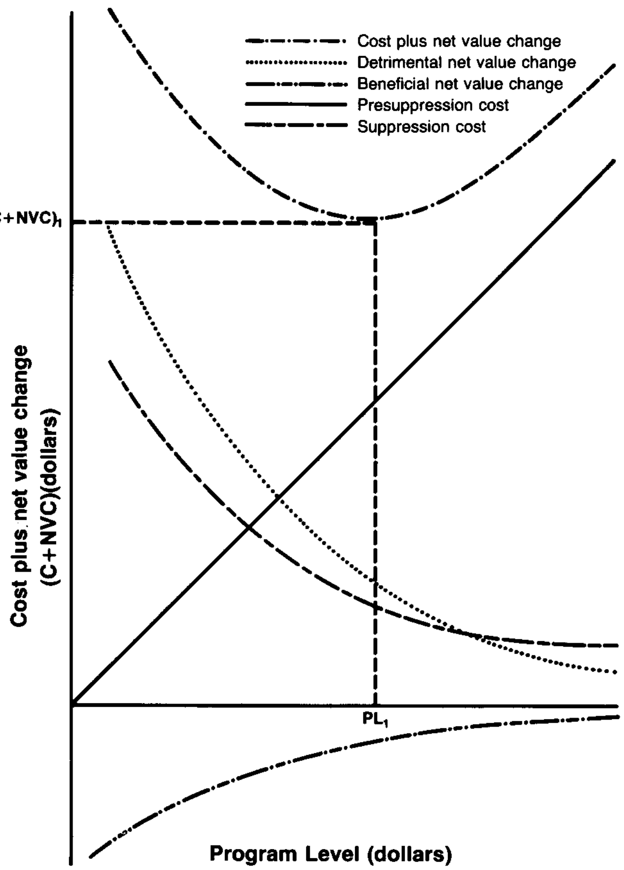


Figure 1--Suppression costs and changes--whether beneficial or detrimental--due to fire diminish as presuppression expenditures increase, according to this model of cost plus net value change.

increasing the fire control activity is a reduction in detrimental fire effects and suppression expenditure.

A review of the fire economics literature (Gorte and Gorte 1979) found little empirical application of the C+NVC model. More recently, however, analyses by Schweitzer and others (1982) and the U.S. Department of Agriculture, Forest Service (1980) applied the model to alternative National Forest System presuppression programs. A Forest Service analysis of presuppression programs on state and private lands has also been completed (U.S. Dep. Agric., Forest Serv. 1982b).

However the C+NVC model has been presented in the literature, the issue of risk is either short-changed or ignored. Variation in outcome, and therefore in the total C+NVC curve, is generally not considered. The fire economics literature which evaluates the proposed models (Davis 1965, Zivnuska 1972) shows awareness of risk, and Schweitzer and others (1982) touched on the issue by evaluating 3 years of varying fire season severity, but the risk-oriented analytical work is sparse. There is general agreement that any comparison between fire controls must consider its effect on outcome probability as well as its expected value economic efficiency. To make such comparisons possible, risk must be incorporated into the model. Before demonstrating how this can be done, however, we need to consider some theoretical principles of risk and uncertainty.

RISK AND UNCERTAINTY IN DECISION THEORY

In its simplest form, the decisionmaking problem is a choice among a set of actions. If all the conditions associated with the action are known and not subject to change, or totally within the decisionmaker's control, then the outcome of any action is a certainty, and the choice is made solely on the basis of the outcome desired. (We assume here that the conditions themselves are not affected by the choice of action). Normally, however, the outcome depends not only on the action chosen but also on unknown factors that are not in the individual's control. Each combination of these unknowns may be called a "state of nature." Based on two possible actions (a_1, and a_2) and two possible states of nature (s_1, s_2) there are four possible outcomes or consequences (C_{11} through C_{22}):

States:	Actions a_1	a_2
s_1	c_{11}	c_{12}
s_2	c_{21}	c_{22}

In a state preference model, the planner's beliefs as to the likelihood of each state of nature are summarized as P_1 and P_2 (*table 1*). These probabilities do not depend on the choice of action. The consequences multiplied by the state probabilities give results which, when summed for each action, provide a measure of the expected values v_1 and v_2 of taking the actions. The planner can compare these expected values, representing the long-term average outcome. The choice is straightforward if the planner simply selects the action with the greatest expected value, that is,

Table 1--*State preference representation of a decision problem*

Alternate actions	States of nature	Possible consequences	X	Probability of state	Expected value of action[1]	Variance
a_1	s_1	c_{11}		P_1	v_1	σ_1^2
	s_2	c_{12}		P_2		
a_2	s_1	c_{21}		P_1	v_2	σ_2^2
	s_2	c_{22}		P_2		

[1]Products of c_{ij} and P_j for each state are summed to equal v_i for each action.

with maximum utility. By the term "utility" we mean the value that the decisionmaker places on the outcome.

Although in this simple model the actions, states, and consequences are shown as discrete, each may be a continuum of values--that is, each may in turn be probabilistic. The states of nature in the fire management system are described by conditions such as weather events and fire occurrence frequency. The actions specified may include fuel treatment actions, suppression strategies, or a mixture of several different program components. The C+NVC consequences, being contingent on probabilistic elements, are also probabilistic.

In applications of the state preference model under risk conditions, the outcome probabilities for each state of nature are known with some degree of precision. Under uncertainty, however, the decisionmaker cannot determine the outcome probabilities. Various decision rules or strategies have been proposed for use under uncertainty, such as the minimax, maximax, or principle of insufficient reason strategies. Because these tend to be inconsistent or unsatisfactory, it is probably more useful to approximate risk conditions whenever possible than to apply uncertainty decision rules. That is, it is helpful to assign some probabilities to the various states of nature, even if these must be arrived at subjectively. For example, moderate to broad resolution estimates of fire behavior and fuelbed conditions were found to be adequate for many data needs in fire planning in a study made on a National Forest (Barrager and others 1982). Highly refined data are not always necessary. For this reason, this discussion of decision theory will consider risk conditions rather than uncertainty.

An action with a certain outcome is a useful benchmark for evaluating the individual's view of the risk associated with other actions with probabilistic outcomes. Thus, if the probabilities for $s_1$are 100 percent, those for s_2 must be 0, and the choice presents no risk. If the consequences c_{11} and c_{21} are identical (action 1 produces the same result under either state of nature), the outcome of action 1 is certain and without risk. Decisionmakers may show indifference between these actions whose outcomes are certain and others with probabilistic outcomes. If they do, the outcome of the certain action is known as the *certainty equivalent,* and it can be used to measure their degree of risk aversion, that is, their unwillingness to take an even bet.

One way to represent degrees of risk aversion that an individual displays using the certainty equivalent is to depict utility functions (*fig. 2*). The horizontal axis, which measures the variance of outcome, represents the degree of risk. Here v_1 is the mean value of a particular event whose outcome is certain (has a zero variance). If the decisionmaker shows indifference between it and the expected value v_2 of an event whose outcome carries risk, (σ_2^2) then the individual's *risk premium is* v_2-v_1. That is, the individual will accept greater variance in the expected outcome only if the outcome has a greater expected value. Each curve traces a locus of such points, called the decisionmaker's *indifference curve.* The parameter (here variance) over which risk preference is shown may take other forms. This general approach for comparing two parameters is termed "parameter preference" (Tobin 1958).

In many specific situations, the decision reached on the basis of parameter preference may be the same as that which simply

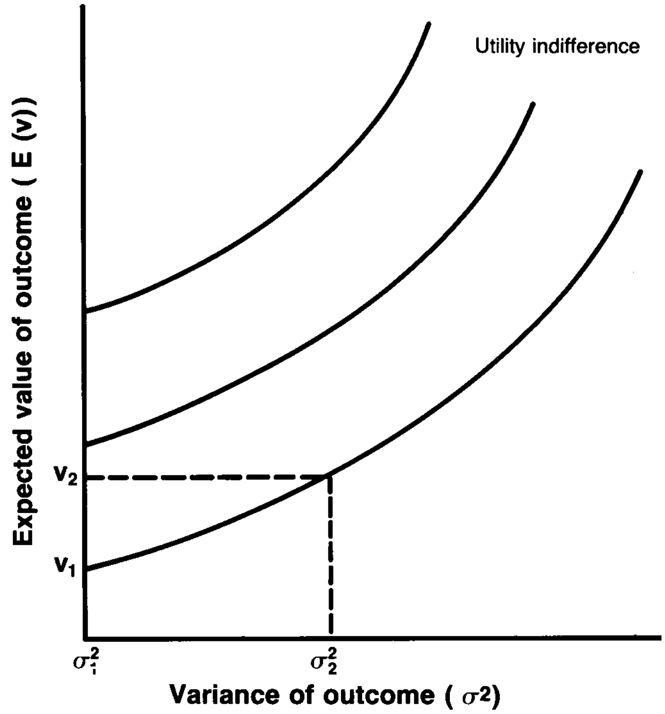


Figure 2--The parameter preference model for mean-variance makes the trade offs between expected value return and return variability explicit.

maximizes the expected value outcome as shown in the state-preference model. In others this is not true (*table 2*). Each action in this example has the same expected value, and the same variance. Risk-averse individuals confronted with this choice, however, would normally select action a_2 to avoid the possibility of the - 8000 consequence, a decision not accounted for by simple parameter preference.

DECISIONMAKER'S APPROACH TO RISK

The attitude of the decisionmaker with respect to risk may range from risk aversion through risk neutrality to risk preferring. In general terms, the purchase of an insurance policy is an illustration of risk aversion; the difference between purchasers'

Table 2--*Example of ambiguity in application of parameter preference to a decision problem*

Alternative actions	Consequences X	Probability of states =	Expected value	Variance of expected value
a_1	c_{11} = 2,000	0.9	1000[1]	9 x 10^6
	c_{12} = -8,000	.1		
a_2	c_{21} = 0	.9	1000[2]	9 X 10^6
	c_{22} = 10,000	.1		

[1]Products of actions a_1, a_2, and states s_1, s_2 (*table 1*).

expected loss and their insurance cost is their risk premium. Gambling, in most instances, illustrates risk preferring. The risk neutral decisionmaker is indifferent to risk and considers only the expected value outcomes in the decision.

Risk Aversion

Risk aversion--the unwillingness to accept a fair bet--can be illustrated (*table 1*). If the consequences of action a_1 are a win (W) under state s_1 and a loss (-L) under state s_2, and those of a_2, an insurance action, are a risk-free cost (D) in both states, then we can express v_1, the expected monetary value of each, in this way:

$$v_1 = (P_1 W) + [P_2(-L)] \text{ and}$$
$$v_2 = P_1[W+(D-W)] + P_2[-L+(D+L) = D$$

A risk-averse decisionmaker would choose action 2, even though its monetary value was less than that of action 1. The risk premium paid for the risk-free insurance option would be v_1 - D.

In the real world, fire managers and public fire management agencies appear to be risk averse. It is reasonable to assume that local fire program decisionmakers are more risk averse than their agencies or than society as a whole because they see more localized sets of cost figures and benefits. To decisionmakers, the probability of adverse outcome is low but its relative impact is great.

Particular conditions may increase risk aversion. Consider, for example, foresters with management experience in various nonfire assignments who are transferred to fire management positions. They may expect their new jobs to be their only fire experience, and they also may expect that their future careers depend on there being no large fires during their tenure. The utility curve will, therefore, reflect acres burned instead of economic value. And that utility curve will also show a greater degree of risk aversion than that for foresters with more fire management experience who intend to stay in a fire position, because foresters with less experience are probably less sure of themselves, and their personal costs of failure are greater.

The prevalence of risk aversion has led to the development of economic institutions for shifting risks, such as market insurance and the issuance of common stocks. Risk sharing is also a response to risk aversion; movement of crews and equipment across public agency boundaries is an example of risk sharing in fire management.

Even in the presence of risk aversion, however, universal full insurance is virtually impossible. Budgets limit the amount of insurance that can be purchased. There is also a condition known as *moral hazard* that hampers full risk sharing. Issuance of insurance can affect the incentives, which in turn affect the probabilities and outcomes, and therefore the risk itself. This is why private timber companies cannot obtain full insurance against forest fires; it would decrease their incentive to control fires.

Risk aversion enters strongly into investment decisionmaking since investment is the exchange of certain returns now for probabilistic returns in the future (Hirshleifer 1965). This is particularly true of long-term investments, such as those typical of natural resource production processes. In the absence of perfect markets, risk averse [sic] individuals may discount probabilistic returns at a higher rate to accommodate risk.

The implications of risk aversion for public investment have been widely discussed. Some economists have contended that public agencies should be risk-neutral because of the diversity of their investments (Samuelson 1964), and because risks are diluted by spreading them along a large number of actors (Arrow and Lind 1970). That is, public agency budgets are large and relatively unconstraining; therefore, agencies with many investments can self-insure against most risks. This approach explains arguments for a risk-neutral fire plan for the National Forest System. Budget levels probably do not limit self-insurance of large timber companies from fire losses, either. Thus, risk neutrality may be justified for both public agencies and large private firms.

Arguments for risk-neutral decisions disregard several factors, however. Moral hazard is one; another is the distinction between institutional objectives and the personal objectives of individual managers. Fire managers whose careers depend on the outcome of their decisions are likely to be risk averse. A third factor is the uneven distribution of benefits and costs. Risk neutral decisions assume that these are uniformly distributed and independent of the states of nature, an assumption that is unrealistic for most public investments, particularly those involving natural resources. Fire protection is more beneficial in dry southern pine forests than in the spruce-fir bogs of Maine. National forest fire protection is also more beneficial to local communities dependent on timber for their livelihood than it is for the general taxpayers who are lumber consumers.

Decision theory is, therefore, relevant to forest fire management. Wildfire management consists of adaption to risk as well as risk sharing. Productive adaptations, like fire roads and fuels management, can change the total risks to be distributed, but risk aversion is still important in local fire management.

The following simple example clarifies some of these concepts. A fire manager confronted with a wildfire may have two alternatives: a_1, monitor fire progress while allowing it to burn, or a_2, take aggressive measures to suppress it. A low intensity fire can have beneficial effects for wildlife habitat and grazing. The outcome under each action and state of nature are these:

Values for actions

States: (Fire intensity)	a_1 (monitoring)	a_2 (aggressive suppression)	Probabilities
s_1 (high)	$10,000	$1,200	0.1
s_2 (low)	-1,000	-900	.9

A positive C + NVC is a net loss, therefore, the expected C + NVC outcome is 100 for a_1 and -690 for a_2. The expected monetary C + NVC's of the two actions might lead the manager to choose the monitoring action. The risk-averse manager, however, may prefer the more certain returns of the aggressive suppression action. The manager's implicit risk premium is at least $790.

Table 3--*Example of a paradoxical group decision based on probabilities and utilities as seen by two risk-neutral individuals*

Decisionmaker	Action	State of nature	Utility[1] (outcome)	Probability	Expected value
Timber company manager	No prescribed burn	Wildfire	9500	0.1	950
		No wildfire	0	.9	
	Prescribed burn	Wildfire	1000	.1	
		No wildfire	1000	.9	[2]1000
Wilderness guide	No prescribed burn	Wildfire	7000	.3	980
		No wildfire	-1600	.7	
	Prescribed burn	Wildfire	1000	.3	
		No wildfire	1000	.7	[2]1000
Group	No prescribed burn	Wildfire	8250	.2	
		No wildfire	-800	.8	[2]1010
	Prescribed burn	Wildfire	1000	.2	
		No wildfire	1000	.8	1000

[1]Expected monetary value of the cost plus net value change. Positive benefits are shown as negative values on this basis.

[2]Acton with the greater expected value.

Group Decisions

Degree of risk preference enters into group decisions in complex ways. Members of the group may differ radically in their preferences and their assessment of the states of nature. For example, fire roads may be desirable to those who want fire control that is aggressive enough to exclude fire from an area, but may be obstacles to those who prefer wilderness preservation.

The paradoxes that arise in group decisionmaking have been described by Raiffa (1970). Consider a choice of whether to do a prescribed burn. A probability exists that a wildfire could occur after the prescribed burn. The probabilities of subsequent wildfire and the utilities as seen by two advisers--one a corporate timerlands [sic] manager and the other a wilderness tour guide--can be contrasted, along with the resulting group decision (*table 3*). For simplicity, both advisers are shown as risk-neutral. Considering a wildfire unlikely, the timberlands manager prefers no prescribed burn. The guide also prefers no burn because the consequences of a wildfire when there has not been a previous prescribed burn are relatively less severe, and there are positive benefits to no fire at all planned or unplanned. A group decision here was obtained by weighting the utilities and probabilities of the two advisers equally. The group decision, based on expected value outcome, favors the prescribed burn. The group decision is the reverse of the individual decisions. This may be a rational choice if the probability assessments are independent of the assessments of the consequences.

INCLUDING RISK IN C +NVC MODEL

The risk aversion that we suggest is present in fire managers and public fire agencies strongly implies that risk must be evaluated and incorporated into policy models such that the trade off between risk and efficiency can be clearly defined. This can be accomplished by including probabilistic considerations and outcomes within the C + NVC model output.

In depicting the model, acres burned is the surrogate measure of fire effects (*fig. 3A*). The curve shows the expected effects of fire management effort on acres burned as they are frequently reported in the literature. The curves at PL_1 and PL_2 are the probability distributions of acres burned at those funding levels. The increased expenditure, then, reduces the expected acres burned and reduces the width of the probability distribution. The risk-averse fire manager will expand the fire management effort beyond the point where its cost equals the reduction in loss.

In *figure 3B,* the probability distributions are shown in relation to the C+NVC curve in *figure 1.* Recalling our discussion of state preference, we assume that the fire manager's problem is to maximize net utility, which is assumed here to be the same as minimizing C +NVC, if risk neutrality prevails. In *figure 3B*, as expenditures on presuppression inputs increase, the probability functions become tighter and risks decrease. Risk averse man-

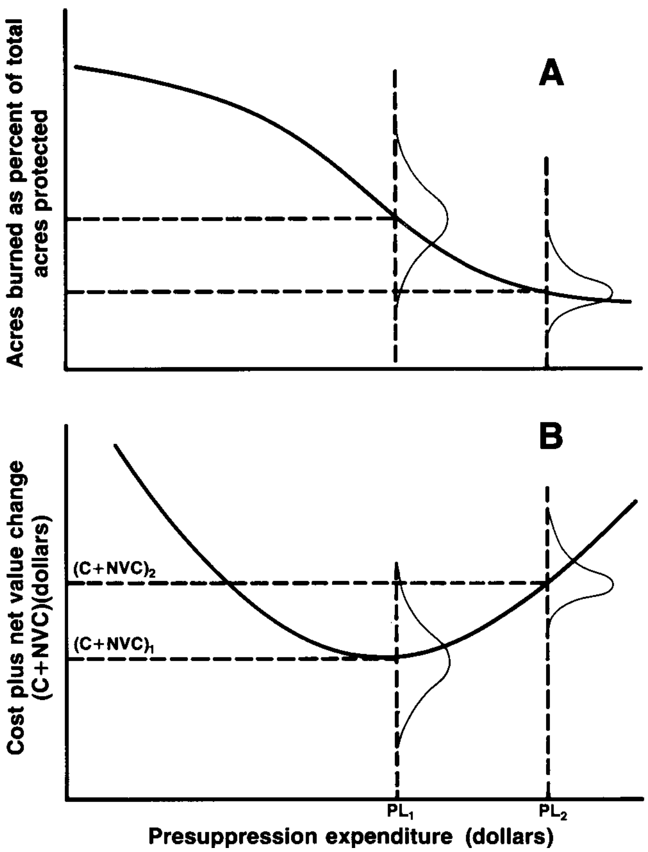


Figure 3--The expected reduction in cost plus net value change variation with increasing presuppression expenditures must be compared with reductions in expected value efficiency beyond the most efficient program level.

agers will extend presuppression effort beyond PL_1, the least cost plus solution. If PL_2 is the chosen level of presuppression expenditure, then $(C + NVC)_2 - (C + NVC)_1$ is the risk premium associated with the reduced risk. Although this model is purely theoretical, it provides a framework for the consideration of data and measurement problems.

DATA AND MEASUREMENT

For eventual development and implementation of a decision-making model that includes a consideration of risk, empirical data must be gathered and analyzed. Certain critical areas of the fire control management problem will need to be considered, such as:

- What are the temporal and spatial units that define the problem?
- What is the appropriate utility curve for fire management?
- What are the control and state variables?
- What are the effects of management actions?

In addition, the probabilities of state variables and the effects dependent on them will need to be estimated.

The measurement units generally selected for time and space are the annual fire season and the fire management area. Annual evaluation of fire damage and fire management is reasonable. It seems important, nevertheless, to include multiple season fire management effects in the annual analysis because there are correlations between fire risk and damages from year to year. The effect of scale may be relevant; the variance in fire effects is reduced over longer time periods, and there are short periods of high risk when fire danger is great.

The fire management area is a more ambiguous unit. It includes land under the jurisdiction of a fire manager for fuels management, prevention, detection, and suppression. It is often determined by physical barriers, but in the absence of these, the fire manager must plan for possible fire spread to adjacent management areas. Again, the scale on which decisions are being made affects risk assessment in fire management. A local fire manager is likely to be more risk averse than one setting national fire policy. The Chief of the Forest Service can accept a single 30,000-acre fire much more easily than a District Ranger. The probability of such a fire somewhere within the National Forest System is much greater than that on a given District, but its effect is much smaller. Therefore, some risk-related policies, such as prescribed burning, might be less attractive to a local fire manager than to a planner at the national level. This fact must be considered if broad social objectives are to be satisfied in public land management planning.

The major utility problem to be solved in natural resource areas is the difficulty of assigning value to the multiplicity of resource outputs that originate on forest land. Many, such as water and range, are not exchanged freely in the market, and some, such as certain types of recreation, are not exchanged at all. Fire managers must also show concern for such values as public safety, air quality, and soil stability.

Additional problems are presented by the fact that the impact of wildfire varies with the character of the fire and the fire site, with the availability of substitute resources, and over time after the fire. Also, fire damage is not always restricted to the fire area, but may include offsite effects, as flooding. The intensity of the fire as well as acreage burned is important, and is not always constant over the total fire area. Low intensity fires can have positive effects, even to the extent of producing a positive net value change in resource output, either initially or several seasons after the fire.

What is the appropriate utility curve for a public land management agency? Perhaps the damages of small fires can be ignored. If large fires are truly unlikely, then they too can be ignored in the general daily management plan and in the evaluation of a local manager's performance. Perhaps the severest events cannot really be planned for in a presuppression sense. Fire managers should concentrate their fire management skills on the broad mid-range of all potential fires. Specifications of the utility curve and the state variables with their probabilities could set bounds on the fire sizes that should be subject to management strategy.

Measurement of fire control and state variables is an easier task than determining utility. Control actions are commonly separated into fuels management, prevention, detection, and suppression variables. Inputs of personnel and equipment within these classes are readily measurable in both physical terms and dollar value. There are also common measures of important state variables, such as wind, weather, fuel volume, and fine fuel moisture content.

Evaluating the outcome of fire management actions presents more serious problems because we must estimate the probability of their various outcomes. The probability of both lightning- and human-caused fire occurrence has been investigated and its distribution has been closely approximated by a Poisson probability function (Cunningham and Martell 1973, Fuguay 1978). Fire spread (Rothermel 1972) and probability of ignition have also been studied in relation to state variables, but unfortunately there has been little empirical work tying these probabilities to the fire control variables. Initial attack effectiveness has been modeled (Albini 1976, Bratten and others 1981, U.S. Dep. Agric., Forest Serv. 1982a). Fireline construction rate estimates vary considerably, however, and the variability can influence effectiveness of both initial attack and large fire suppression actions (Haven and others 1982). These relationships must be better understood if fire controls are to be evaluated with respect to risk.

These comments on data and measurement problems are presented in terms of the model presented earlier. Considerable amounts of additional data are needed before the model can be fully developed empirically. Even with present data, however, empirical application can be made to small subsets of the forest fire problem.

RISK AND HAZARD MANAGEMENT

Fire is only one of the natural hazards that managers of both public and private lands must address. A review of the characteristics, costs, damage, and control timing of snowstorms, floods, oilspills, and forest fires permits us to identify unique features of fire management (*table 4*). It would be instructive to make a similar analysis for a more complete list of natural hazards, including earthquakes, volcanos, hurricanes, urban fires, droughts, and others.

The damage characteristics of natural hazards are based on a combination of the hazardous event and the existing state of human adjustment. The local inhabitants of the area north of the Arctic Circle have adjusted thoroughly to snowstorms, events which are hazardous but seldom catastrophic. Where hazards tend to be catastrophic, development is limited, so that damage is held at a low level. The potential for nuclear accidents to be catastrophic explains why nuclear facility designers display greater risk aversion than do planners for controlling the various damaging but noncatastrophic natural hazards. (Starr 1969).

Forest fires resemble other hazards, but also differ from them. Several features of forest fire damage distinguish it from other hazardous events. First, the potential fire damage is complex, because of the multitude of goods and services originating in forests. Second, fires can alter the array of these goods and services for a number of years, with the unique characteristic that the alteration may be beneficial.

Table 4--*Characteristics, costs, damage, and control timing of some unavoidable natural hazards*

Feature	Hazard
	Snowstorms
Characteristics	Recurring, seldom catastrophic, not preventable, but can be forecast
Costs	Long-run investment in equipment and manpower, short-run cost for immediate response
Damage	Variable, short-lived
Control timing	Before event: minimal (weather monitoring, structural modification) During and after event: snow removal
	Floods
Characteristics	Recurring, seldom catastrophic, not preventable but can be forecast; also control of development of floodplain
Costs	Long-run investment in equipment and manpower, short-run cost for immediate response; also dams, levees, and costs of development foregone
Damage	Variable, relatively short-lived
Control timing	Before event: weather forecasts, reports of upstream river conditions During and after event: some levee building, rescue and relief, cleanup
	Coastal oilspills
Characteristics	Recurring, rarely catastrophic, preventable (avoid development)
Costs	Cost of opportunity foregone; short-run cost for cleanup equipment and manpower
Damage	Variable, some immediate, some potentially lasting
Control timing	After event: cleanup
	Forest fires
Characteristics	Recurring, seldom catastrophic, some preventable
Costs	Long-term investment in equipment and manpower short-term cost of immediate response
Damage	Variable, can be long-lasting, may be ultimately beneficial
Control timing	Before, during, and after event: fuel modification, suppression activities, cleanup and salvage

In general, controls for most hazards concentrate on one or another of the three control periods specified in *table 4* (before, during, or after the event has occurred). Secondary controls are often applied at a different time than primary controls, however. The third unusual feature of fire management is that available actions are unusually varied and may occur in any or all three periods, before, during, and after the hazard event. Prevention, fuels management, weather forecasting, and presuppression activities occur before fire ignition; detection and suppression occur during the fire; and timber salvage and erosion control occur after the fire. Activities affect the likelihood and intensity of fire, and the magnitude of the damage. Suppression currently receives the bulk of attention, but fuels management is growing in importance.

While this diversity of control options does not suggest that forest fire managers can ignore risk, it does show there is greater flexibility for managing the risk than is typical of other hazardous events. The long-term forecasts and heavy capital investment necessary in flood management, for example, which suggest early and strongly risk averse decisions, are largely absent. Nor are fire controls as simply reactive and delayed as are snow removal actions. Greater variety in control options enables fire managers to operate closer to their mean expectations of damages due to the event; that is, to be less risk averse. It also requires careful evaluation of trade offs between the various control options.

Any comparison of forest fire control with control of other natural hazards must consider how decisionmakers plan for the riskiness of various perils. Where probability distributions and economic costs and damages are uncertain, we find general reliance on ad hoc criteria that imply an acceptable level of risk. Pollution and flood control planning can be examined to determine how these criteria compare with those common in fire control.

Congress has applied three different canons in legislation on the effects of environmental pollution on human life. The 1963 Clean Air Act applies *a health-based* standard, by which the maximum acceptable pollutant level is that at which the population group most sensitive to air pollution is not affected; this is reduced by a "margin of safety" to protect against undetected dangers (Thompson 1979). Such a standard implies either an infinite value on human life or the most extreme form of risk aversion. The 1972 Federal Water Pollution Control Act applies *a technology-based* standard, by which technological and economic feasibility dictate level of abatement (LaPierre 1977). This imples [sic] a greater acceptance of risk, as industries have little incentive to produce new technologies to clean up their wastes. The third canon is a *combination* of the two. The 1977 Noise Control Act and the 1974 Safe Drinking Water Act require consideration of both public health and economic-technical feasibility (LaPierre 1977). Most legislation takes this intermediate course, but the emphasis either way varies.

Legislation affecting flood planning takes a different tack. Federal funding encourages preparation of local disaster plans for such events as hurricanes, which lead to flooding at the time of the storm. In addition, the 1968 National Flood Insurance Act makes insurance available to communities with development guidelines for flood-prone areas. Recent amendments also prohibit Federal funds from supporting uninsured development in such areas. The decrease in development incentive decreases risk of losses from flooding (Baker 1979).

Similar standards have been employed with fire. An early Forest Service example is the 1934 policy to control all fires during the first burning day which avoids the risk of less favorable weather conditions the next day. Another early standard was the Forest Service's 1972 planning criterion of building a presuppression program capable of suppressing fires that occur under specified conditions (the 90th percentile burning index that occurred in the fourth worst of the last 10 years) at 10 acres or less (U.S. Dep. Agric., Forest Serv. 1977). The Forest Service fire management policy was revised in 1978 to mandate that the fire management program should be "cost efficient and responsive to land and resource management goals and objectives" (U.S. Dep. Agric., Forest Serv. 1983). The corresponding fire suppression policy states that the selection of suppression actions must consider cost effectiveness and probabilities of success.

Although the revised fire management policies and standards are not as concise and unambiguous as the earlier physical fire standards, they require a more thorough evaluation of the trade offs between risk and other objectives, such as the cost-effective contribution to land and resource management objectives. The presence of data and measurement problems and an incomplete model design are obstacles to such risk evaluation, but previous studies (Schweitzer and others 1982) demonstrate that some quantitative risk analysis is possible. The design of a probabilistic fire management analysis model by Bratten (1982) and Mills and Bratten (1982) provides further evidence that fire risk evaluations are feasible.

REFERENCES

Albini, Frank A. **Computer-based models of wildland fire behavior: a user's manual.** Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1976. 68 p.

Arnold, R. K. **Economic and social determinants of an adequate level of forest fire control.** Ann Arbor, MI: University of Michigan; 1950. Dissertation.

Arrow, K.J; Lind, R.C. **Uncertainty and the evaluation of public investment.** Amer. Econ. Rev. 60:364-378; 1970.

Baker, E.J. **Geological variations in hurricane risk and legislative response.** Coastal Zone Manage. J. 15(4):263-283; 1979.

Barrager, Stephen M.; Cohan, David; Roussopoulos, Peter J. **The economic value of improved fuels and fire behavior information.** Res. Pap. RM-239. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 32 p.

Bratten, Frederick. **Probability model for analyzing fire management alternatives: theory and structure.** Gen. Tech. Rep. PSW-66. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 11 p.

Bratten, Frederick W ; Davis, James B.; Flatman, George T.; Keith, Jerold W.; Rapp, Stanley R.; Storey, Theodore G. **FOCUS: afire management planning system--final report.** Gen. Tech. Rep. PSW-49. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1981. 34 p.

Cunningham, A.A.; Martel, D.L. **A stochastic model for the occurrence of man-caused fires.** Can. J. Forest Res. 3(2):282-287; 1973.

Davis, Lawrence. **The economics of wildlife protection with emphasis on fuel break systems.** Sacramento, CA: California Division of Forestry. 1965. 236 p.

Deeming, John E.; Burgan, Robert E.; Cohen, Jack D. **The National Fire-Danger Rating System--1978.** Gen. Tech. Rep. INT-39. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1977. 63 p.

Fuquay, Donald M. **Predicting ignition of forest fuels by lightning.** In: Proceedings of the fifth joint conference on fire and forest meteorology; 1978 March 14-16; Boston, MA. Boston, MA: Amer. Meteorol. Soc.; 1978: 32-37.

Gorte, Julie K.; Gorte, Ross W. **Application of economic techniques to fire management. A status review and evaluation.** Gen. Tech. Rep. INT-56. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1979. 26 p.

Haven, Lisa; Hunter, T. Parkin; Storey, Theodore G. **Production rates for crews using hand tools on firelines.** Gen. Tech. Rep. PSW-62. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 8 p.

Headley, Roy. **Fire suppression manual, District 5:** Washington, DC: U.S. Department of Agriculture, Forest Service; 1916. 58 p.

Hirshleifer, J. **Investment decision under uncertainty: choice theoretic approaches.** Quart. J. Econ. 79(4):509-536; 1965.

Hornby, Lloyd G. **Fire control planning in the northern Rocky Mountain region.** Prog. Rep. NRMFRES-1. Washington, DC: U.S. Department of Agriculture, Forest Service; 1936. 37 p:

Knight, Frank H. **Risk, uncertainty and profit.** Boston: Houghton Mifflin; 1933. 381 p.

LaPierre, D.B. **Technology-forcing and federal environmental protection statutes.** Iowa Law Rev. 62(3):771-838; 1977 February.

Mills, Thomas J. **Economic evaluation of alternative fire management programs.** In: Barney, Richard J., ed. Proceedings of the symposium on fire control in the 80's; 1979 October 30-November 1; Missoula, MT. Missoula, MT: Intermountain Fire Council; 1979: 75-89.

Mills, Thomas J.; Bratten, Frederick W. **FEES: design of** a **Fire Economics Evaluation System.** Gen. Tech. Rep. PSW-65. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 26 p.

Raiffa, H. **Decision analysis.** Reading, MA: Addison and Wesley; 1970. 309 p.

Rothermel, Richard C. **A mathematical model for predicting fire spread in wildland.** Res. Pap. INT-115. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1972. 40 p.

Samuelson, Paul A. **Discussion.** In: Proceedings of the seventy-sixth annual meeting of the American Economic Association; volume 54(3); 1963 December 27-29; Boston, MA. Boston, MA: Am. Econ. Assoc.; 1964: 93-96.

Schweitzer, Dennis L.; Anderson, Ernest V; Mills, Thomas J. **Economic efficiency of fire management programs at six National Forests.** Res. Pap. PSW-157. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1982. 29 p.

Simard, A.J. **Wildland fire management: the economics of policy alternatives.** For. Tech. Rep. 15. Ottawa, Canada: Forest Fire Research Institute, Canadian Forestry Service, Department of Environment; 1976. 52 p.

Sparhawk, W N. **The use of liability ratings in planning forest fire protection.** J. Agric. Res. 30(8):693-762; 1925 April.

Starr, C. **Social benefit versus technological risk.** Science 165: 1232-1238; 1969.

Thompson, Kenneth H. **Margin of safety as a risk-management concept in environmental legislation.** Columbia J. Environ. Law 6(1): 1-29. 1979 fall.

Tobin, J. **Liability preference as behavior towards risk.** Rev. Econ. Studies. 25(67): 65-86; 1958.

U.S. Department of Agriculture, Forest Service. **Evaluation of fire management activities on the National Forests.** Washington, DC; 1977. 127 p.

U.S. Department of Agriculture, Forest Service. **National Forest System fire management budget analysis.** Washington, DC: Aviation and Fire Management Staff, Forest Service, U.S. Department of Agriculture; 1980. 29 p.

U.S. Department of Agriculture, Forest Service. **FSH 5109-19--Fire management analysis and planning handbook.** Washington, DC; 1982a.

U.S. Department of Agriculture, Forest Service. **Fire protection on non-Federal wildlands.** 1982b. Unpublished draft supplied by authors.

U.S. Department of Agriculture, Forest Service. **FSM Title 5100--Fire management. 5103--Policy.** Washington, DC; 1983.

Zivnuska, John A. **Economic tradeoffs in fire management.** In: Proceedings of the symposium on fire in the environment; 1972 May 1-5; Denver, CO. FS-276. Washington, DC: U.S. Department of Agriculture, Forest Service; 1972: 69-74.

The Forest Service, U.S. Department of Agriculture, is responsible for Federal leadership in forestry. It carries out this role through four main activities:

- Protection and management of resources on 191 million acres of National Forest System lands.
- Cooperation with State and local governments, forest industries, and private landowners to help protect and manage non-Federal forest and associated range and watershed lands.
- Participation with other agencies in human resource and community assistance programs to improve living conditions in rural areas.
- Research on all aspects of forestry, rangeland management, and forest resources utilization.

The Pacific Southwest Forest and Range Experiment Station

- Represents the research branch of the Forest Service in California, Hawaii, and the western Pacific.

Blattenberger, Gail; Hyde, William F.; Mills, Thomas J. **Risk in fire management decisionmaking: techniques and criteria.** Gen. Tech. Rep. PSW-80. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1984. 9 p.

In the past, decisionmaking in wildland fire management generally has not included a full consideration of the risk and uncertainty that is inherent in evaluating alternatives. Fire management policies in some Federal land management agencies now require risk evaluation. The model for estimating the economic efficiency of fire program alternatives is the minimization of the sum of fire management cost plus the fire-induced net value change in the resource outputs (C + NVC). Risk can be graphically displayed in this model by the addition of probability distributions about the C + NVC curve. Risk aversion, rather than risk neutrality or risk preference, is widely practiced in fire management, but attitudes toward risk can vary. Managers have greater flexibility in managing fire hazards than other natural hazards because their actions can take place before, during, and after the hazard event. This flexibility enhances their ability to be risk-neutral toward the fire hazard. Although data and measurement problems exist and model design is incomplete, an analytical evaluation of risk inherent in fire management alternatives is feasible.

Retrieval Terms: economic efficiency, expected value decisions, probabilities, risk, state preference, uncertainty