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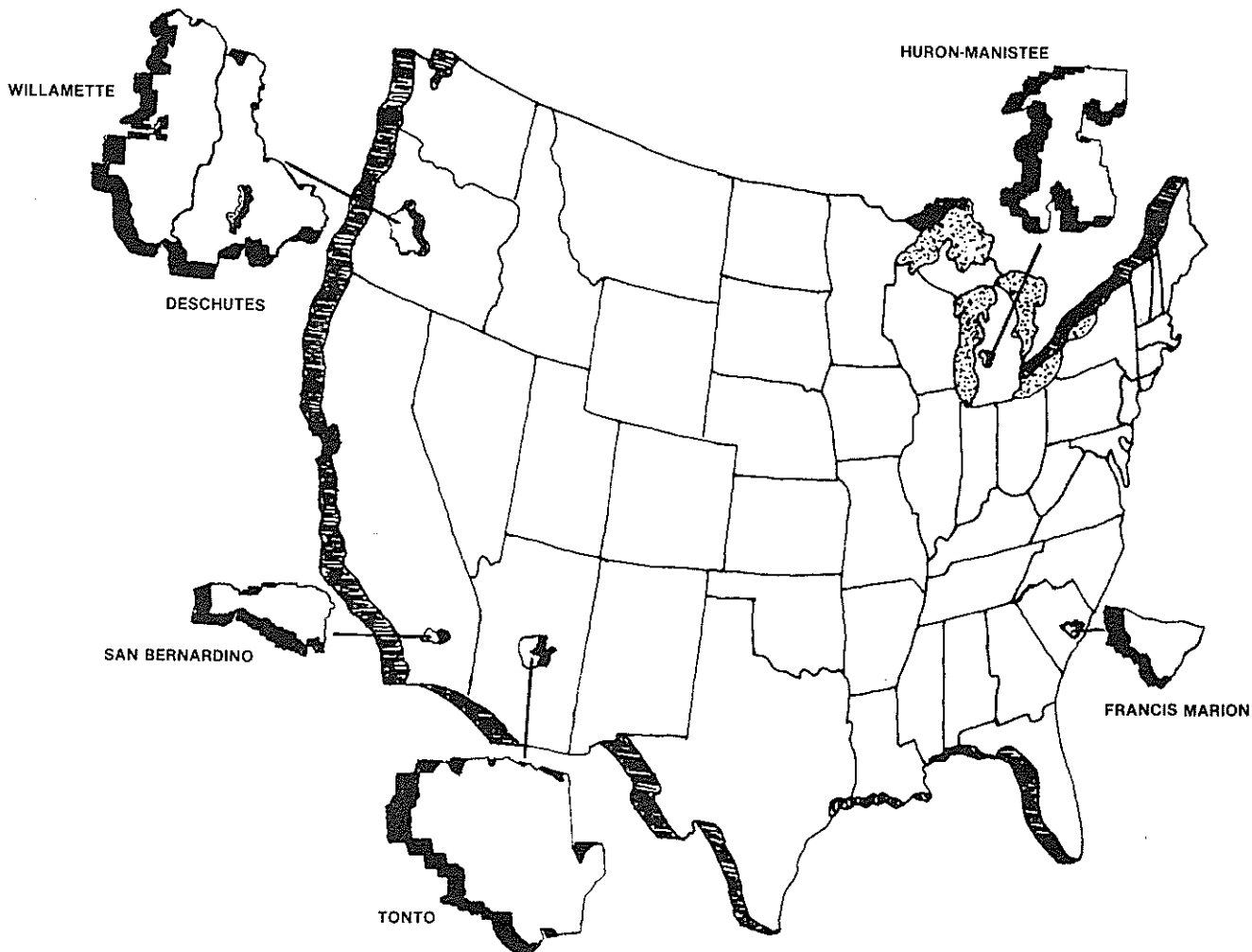
Economic Efficiency of Fire Management Programs at Six National Forests

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Foreword:

This paper reports on the first national scope economic analysis of the fire management program on National Forests. Subsequent national scope study has been completed which includes some of the conceptual advances proposed here. This paper documents an important step in the evolution of more complete economic evaluation capability for fire management programs.

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IN BRIEF...

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The economic efficiency of the initial attack and aviation component of the fire management program on six widely placed National Forests was evaluated using a marginal analysis format. The cost of an increment to the initial attack and aviation program was compared to the resulting change in the fire suppression costs and the net value of resource output and structures. Minimization of the program cost plus the net change in the value of resource outputs and structures ($C + NVC$) was the economic efficiency criterion used to implement this marginal analysis.

Four program or budget levels (PL_1 through PL_4) were evaluated. The program levels varied from 20 percent below the fiscal year 1979 funding level to 40 percent above the 1979 funding level at approximately 20 percent increments. Each program level was evaluated for 3 years of varying fire year severity from relatively low (Year A) through relatively high (Year C) on each Forest, with the exception of 2 years on one Forest where data were limited.

Each of the six Forests is a unique combination of fuels, fire severity, access, resource characteristics, and many other factors which influence fire program efficiency. In spite of this diversity, there are some common results among the case studies. This commonality is an argument for the possibility that the results may apply to areas beyond these six Forests.

There were four categories of results from this study. First, the lowest program level tested (PL_1) was the most efficient in the majority of the simulated fire years, 12 out of 17 years. PL_1 was the most efficient initial attack and aviation program level tested in all years simulated on three of the six Forests: the Francis Marion (in South Carolina), the Huron-Manistee (in Michigan), and the Deschutes (in eastern Oregon). PL_1 was the most efficient on the San Bernardino (in southern California) except in the most severe fire year (Year C). In the future, if Year C occurs less frequently than 2 years in 3, PL_1 will also be the most efficient long-term program level.

The highest program level (PL_4) will be the most efficient program on the Willamette (in western Oregon) if Year C occurs as frequently as 1 year in 5. If the severe Year C occurs less frequently than every 5 years, the lowest program level tested (PL_1) will be the most effi-

cient long-run program on the Willamette too. PL_3 was the most efficient program on the Tonto (in Arizona) in all 3 fire years, due largely to the reductions in suppression costs which result from the increase in initial attack and aviation program input.

Second, the most efficient initial attack and aviation program level was not affected by the severity of the fire year in four of the six Forests: The Francis Marion, the Huron-Manistee, the Deschutes, and the Tonto. The fire year severity had a marginal effect on the most efficient program level on the San Bernardino. Only on the Willamette did the severity of the fire year have a major influence on which program level was the most efficient.

One implication of this result is that economically justifiable requests for supplemental appropriations for the presuppression program in severe fire years may be small. Increased fire year severity may not mean a higher program level is more efficient. Conversely, presuppression budget savings may be small in years of low fire severity even if it were possible to predict severity far enough in advance to make substantial changes in presuppression expenditures.

Third, the simulated fire suppression cost dropped in response to increases in the initial attack and aviation program level in all case studies. The amount of the decline varies from very little on the Francis Marion to a substantial decline on the Tonto. This result is in strong contrast to the historical rise in suppression costs that occurred at the same time that presuppression budgets were increasing.

Fourth, the net value change of resource outputs and structures caused by the fires was a very small percentage of the total $C + NVC$ in 13 of the 17 years studied. The net value change was a moderate percentage of the total on the Deschutes (Year C) and the Tonto (Year A). They were a substantial percentage on the Willamette (Year C) and the San Bernardino (Year C). Even in these 4 years when the net value change was a noticeable percentage of the total, the net value change usually did not drop enough in response to increases in the initial attack and aviation program to cover the cost of the program increment.

The most efficient initial attack and aviation program level was insensitive to reasonable changes in either per unit resource values or fire effect estimates. This indicates that the impact of potential errors in these two model components is not as great as it was previously thought to be. The vast majority of the net value change was the loss of commercial timber and structures. This general result was also found in a recent efficiency analysis of the fire management program on 41 separate National Forests (U.S. Dep. Agric., Forest Serv. 1980b), but in that study beneficial effects on wildlife outputs were also relatively large. While there has been considerable discussion about the value of many wildland resource outputs, the per unit value of commercial timber and structures seldom has been at the center of the debate.

The cost of the fire management organization in the Forest Service, U.S. Department of Agriculture, has increased substantially in recent years. This increase, and continuing concern about the efficiency of all government programs, has led to questions about the economic efficiency of the fire program.

Forest Service fire management obligations for presuppression activities rose from \$44 million (1972 constant dollars) in 1969 to \$110 million in 1977. Obligations for fire suppression fluctuated from year to year, largely in response to variations in fire year severity, but they also show an upward trend, reaching \$105 million in 1977. Total acres burned fluctuated from year to year, but showed no notable decline in response to the increases in obligations (*fig. 1*) (U.S. Dep. Agric., Forest Serv. 1973, 1978a, 1979a, 1980a).

In 1975, the Office of Management and Budget requested the Forest Service to identify the fire management practices which are best as shown by an evaluation of appropriate costs and results. The real program cost trends were documented but the "best" practices could not be identified, largely because no adequate analysis procedure existed (U.S. Dep. Agric., Forest Serv. 1977).

In 1978, the Forest Service revised its fire protection policy. The revised policy requires that the fire management program be cost-effective and compatible with land management objectives (U.S. Dep. Agric., Forest Serv. 1978b). Rapid implementation of the revised policy was difficult, however, again largely because there were no adequate analytical tools capable of evaluating the efficiency of alternative fire management programs.

During the review of the Forest Service's fiscal year 1979 fire management budget request, questions about the fire program efficiency arose again. The United States Senate Appropriations Committee said "presuppression costs have risen dramatically in recent years, but the Committee is unable to discern any marked benefits stemming from these expenditures" (U.S. Senate 1978).

The fiscal year 1979 fire management appropriation was \$24 million less than the budget request. Line item appropriations were prepared for five separate com-

ponents of the fire program which before this time were combined in a single line item. This greater budget detail reduced flexibility in program execution. The *appendix* provides examples of items included in each line item. The United States Congress also directed the Forest Service to conduct "an analysis of the benefits of both fire presuppression and suppression activities and consider such in developing future budget requests" (U.S. Congress 1978). This analysis was initiated as a preliminary response to that request.

The objective of this study was to estimate the economic efficiency of two fire program components—attack force and aviation operations—at several alternative program levels on six diverse National Forests. Other program components must be considered in the final determination of program composition, and even

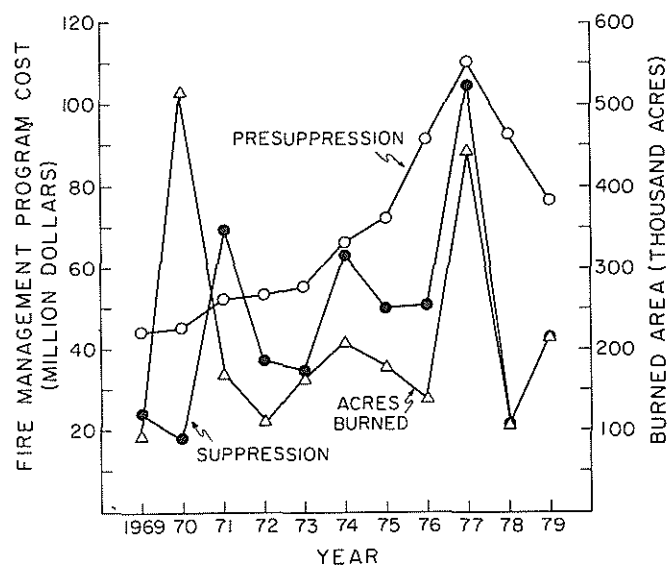


Figure 1—Fire management obligations for fire protection (presuppression) and fighting forest fires (suppression) for the Forest Service are compared with acres burned inside the Forest Service protection area, 1969-1979.

six widely diverse Forests cannot provide analyses extensive enough to direct program decisions on a national scope. These case study results do, however, provide illustrations which should help guide deliberations on the fire program size and structure.

An important constraint of this analysis was the need to complete it in 2 to 4 months. This constraint dictated the use of available data and analytical tools. Because analysis models for the initial attack and aviation operation components were available, the efficiency analysis was restricted to those program components.

This was the first economic efficiency analysis of fire management programs which responded to the concerns expressed by the U.S. Congress and the Office of Management and Budget. Building on the experience gained, a follow-up study of 41 National Forests was made the next year (U.S. Dep. Agric., Forest Serv. 1980b). A handbook procedure for analyzing fire management programs, which incorporates many points from both of those analyses, is now available (U.S. Dep. Agric., Forest Serv. 1980c).

COMPONENTS OF A FIRE MANAGEMENT ANALYSIS

Before considering the study methods and results of this analysis, we need to examine the basic concepts applicable to economic analyses of fire management programs. It is particularly important to identify the types of information which should be provided. As a minimum,

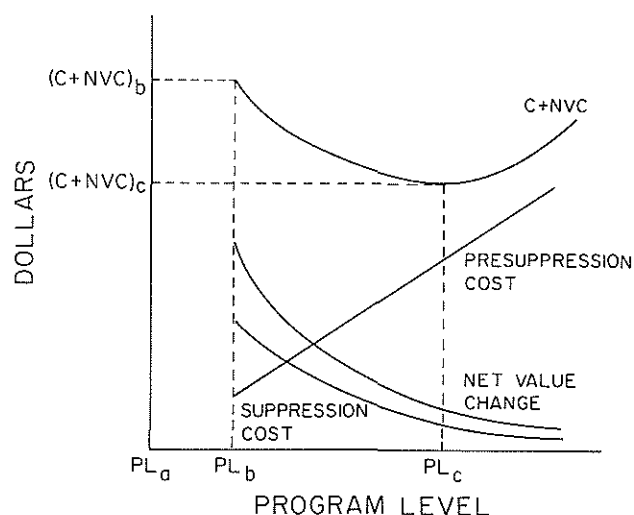


Figure 2—The model for cost plus net value change by fire management program level shows that the most efficient program level for the situation shown is PL_c .

three categories of information should be developed for each fire management alternative evaluated: a measure of economic efficiency, a display of the risk associated with each program selection, and a display of the impacts of fires upon resource outputs. Additional information such as secondary impacts on employment and income, impacts on income distribution, and energy costs would also be useful.

Although the attributes described in this section should be considered in any fire economic analysis, all studies do not successfully include them, and this study does not either. They do, however, provide the context for evaluation of this study's results.

Economic Efficiency

The most efficient fire management program level is the one where the sum of the program costs (both presuppression and suppression costs) and the net value change of resource outputs is minimized, PL_c in figure 2. Gorte and Gorte (1979) describe the evolution of the cost plus net value change ($C + NVC$) criterion from its first application to fire programs in 1925. This criterion is well suited to fire program evaluation because of the way net value change is derived. The other more common financial return measures, such as benefit/cost and present net worth, can be derived from the components of the $C + NVC$ calculation (Mills 1979).

Net value change is defined as:

$$\sum_{i=1}^n (VQ_{Ai} - VQ_{Pi})$$

where

i = resource category

VQ_A = value of resource outputs in the absence of fire

VQ_P = value of resource outputs in the presence of fire

The net value change can therefore be either positive, for detrimental fires that reduce resource outputs, or negative, for beneficial fires that increase outputs above the "no fire" level. A negative sign for an output gain may seem the reverse of conventional practice, but it permits the addition of net value change directly to cost.

The definition of net value change using a "no fire" benchmark is somewhat different from the typical program evaluation structure which compares the output "with" the fire management program to the output "without" the program. The "no fire" benchmark addresses the difficulty of estimating how large fires would actually become if no fire management organization existed, PL_a in figure 2. The implication of this net value

change definition is that fire programs can only be evaluated through a marginal analysis format, by which the efficiency of one program level is compared to that of another. No efficiency conclusions can be reached from the evaluation of a single program level alone, for example PL_b .

The suppression cost and net value change are calculated only for the area burned by the fire plus the direct offsite effects of that burned area. The $C + NVC$ calculation for each program level does not include an estimate of the net value changes or suppression costs that would have occurred if any fires had grown larger. Fires are often suppressed while burning in low value areas so they will not spread into high value resources.

The marginal analysis implications of the $C + NVC$ criterion covers this consideration, however. No conclusion can be drawn from the results of a single program level simulation. Efficiency conclusions can only be drawn from a comparison of programs. If, at a lower program level, the fires can still be suppressed before they reach the high value resources, the lower program level is more efficient. If, at the lower program level, the fires spread into the higher value resource, the net value change and $C + NVC$ for that program level will be higher. The impact of the potential spread of fires into high value resource areas is thus included in the analysis through an incremental evaluation of several different fire management program levels.

At the minimum point on the $C + NVC$ curve, the change in present net worth of the fire program between two PL 's is equal to the difference in the $C + NVC$'s, for example, $(C + NVC)_c - (C + NVC)_b$. This is still an incremental or marginal estimate of program efficiency; an estimate of the return to the total program would be derived from $(C + NVC)_c - (C + NVC)_a$ (Mills 1980).

The minimization of $C + NVC$ is a valid economic efficiency criterion for marginal analysis but that is all it is. One reason why the economic analysis of fire programs has evolved slowly is that a model capable of yielding the relationships in *figure 2* has not been available.

Such a model should include the several components or modules shown in *figure 3*. A description of the resource, topography, and fuel characteristics of the planning area are model inputs. The fire occurrence and weather characteristics, preferably in the form of probability distributions, are also model inputs. The model must contain a fire behavior processor or module to transform the weather, terrain, and fuel loading input into fire behavior characteristics such as fireline intensity and forward rate of spread. The fire behavior module, in combination with the module which estimates the effectiveness of the fire management program inputs, must yield a description of the fires at the point of containment. The fire behavior output and model input on resource character are together the input to the fire effects module. The fire effects output is a description of

the fire impact on resource output levels through time. The per unit resource values are assigned in the resource value module which yields the net value change estimate. This estimate, in combination with the estimate of fire management program cost, provides the $C + NVC$ estimate for a single program configuration applied to a planning area.

When used for the evaluation of program alternatives, this model must be operated over the total number of fire ignitions occurring throughout the season in the area served by the inputs of the fire management program. One simulation through the model for a given fire management program and a season's fires produces one point on the $C + NVC$ curve. Each of the fire management inputs available is then increased or decreased by a given increment, and another simulation of fire program efficiency and $C + NVC$ is made. This produces a second point on the $C + NVC$ curve. The simulations must then be repeated until the minimum $C + NVC$ is located.

Risk

The total number of fire ignitions varies from season to season as does the dispersion of the fire ignitions among the fuel, terrain, and resource classes within an area. Fire-related weather conditions also vary, particularly windspeed and fuel moisture. Although all of these parameters can be important determinants of the most efficient fire management program, they cannot be satisfactorily predicted. To be useful in decisions about the size and composition of the overall fire management program, therefore, they should ideally be included stochastically as entire probability distributions rather than as single point estimates. They should be incorporated throughout the model in such a way that the probability distribution of $C + NVC$ can be derived. The expected value $C + NVC$ can then be estimated by weighting each possible $C + NVC$ by its respective probability of occurrence. The fire program level and composition which has the minimum expected value $C + NVC$ is the most economically efficient in the long run, although it may lead to a less than optimum program level for a single year.

The distribution of $C + NVC$ provides important information about the risk associated with each program decision. How that risk is assessed depends on the decisionmaker's view of risk-taking. A decisionmaker who is risk-adverse may select the fire program which produces an expected value $C + NVC$ within 10 percent of the minimum $C + NVC$ and which also has the lowest probability of a $C + NVC$ twice as large as the minimum. Even if he works on the basis of expected value, a decisionmaker needs estimates of the probability that fire suppression costs and fire effects will be substantially above or below the expected value estimate.

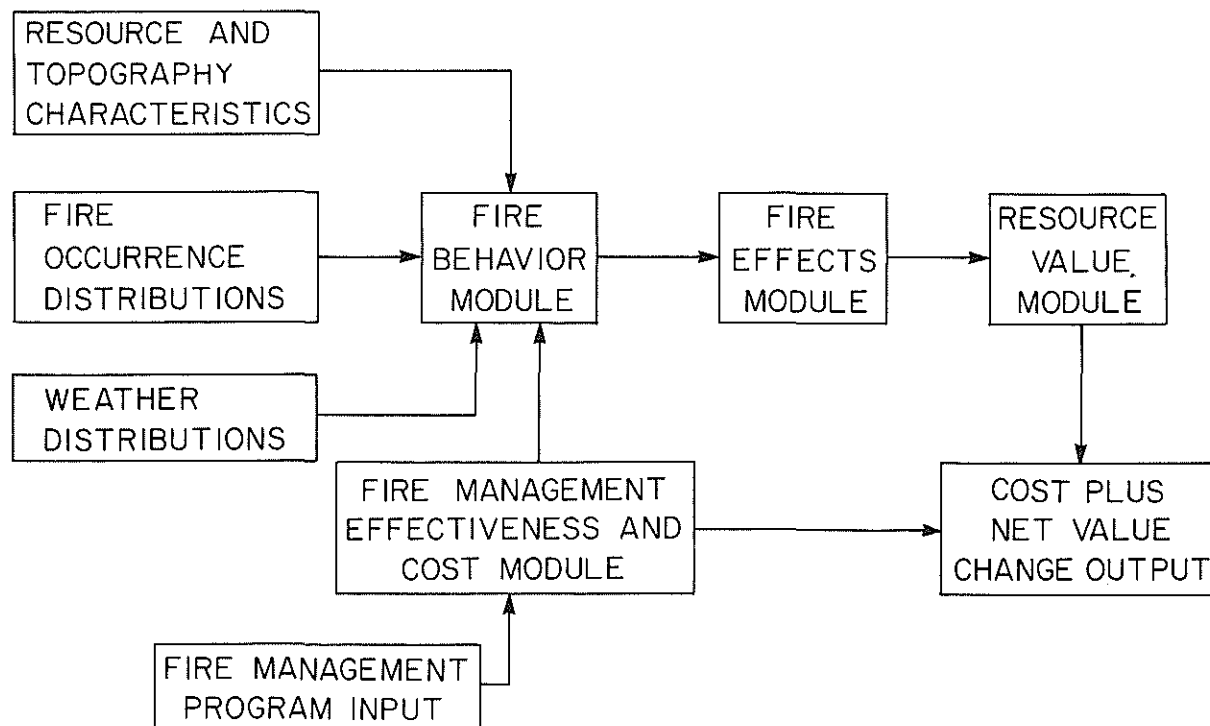


Figure 3—A complete fire economic evaluation model includes these basic components.

The probabilistic aspect of fire management programs may be addressed through complete joint probability functions or simply by evaluating several conditions of varying fire severity. The important point, however, is that the variability of program efficiency resulting from this underlying variation in fire weather and fire occurrence must be explicitly evaluated. Selecting and evaluating only an “average” year or an “average worst” year is inadequate.

Resource Impacts

The net change in resource outputs caused by fire, and the value of that resource output change is included in the net value change component of the $C + NVC$ calculation. The resource output impacts are often important decision parameters themselves, however, so they should be reported separately. Land management objectives are often expressed directly in terms of resource output targets. The fire program impact on those outputs must be estimated to permit a full integration of the fire program within the whole of integrated land management (Nelson 1979). Ideally, the estimates of resource output impacts should be displayed as impacts across time for several resource categories such as commercial timber, recreation, and usable water.

The resource output estimates also provide information on the incidence of the fire program impacts on

potential user groups. The relative impacts on the timber industry, recreationists, and the agricultural sector which is dependent upon irrigation water, for example, can be inferred from the resource impact estimates in combination with income and employment multipliers.

Even though economic efficiency, risk, and resource impact information produced through fire program economic analysis would be very valuable in making fire management program decisions, that is only part of the information needed to make fire program decisions. Additional factors such as social and environmental impacts should also be assessed before the fire management program decision is made. An economic model yielding efficiency, risk, and resource impact estimates would therefore only yield a partial analysis, but then that’s all any analytical process can provide.

STUDY METHOD AND SCOPE

Alternative program levels for the initial attack force and aviation operation portions of the Forest Service presuppression appropriations were evaluated in this study. These are budget line items 113 and 114 (*app.*). The other presuppression program components, fire prevention (item 111), fire detection (item 112), and fuel reduction (item 115), were assumed constant in this

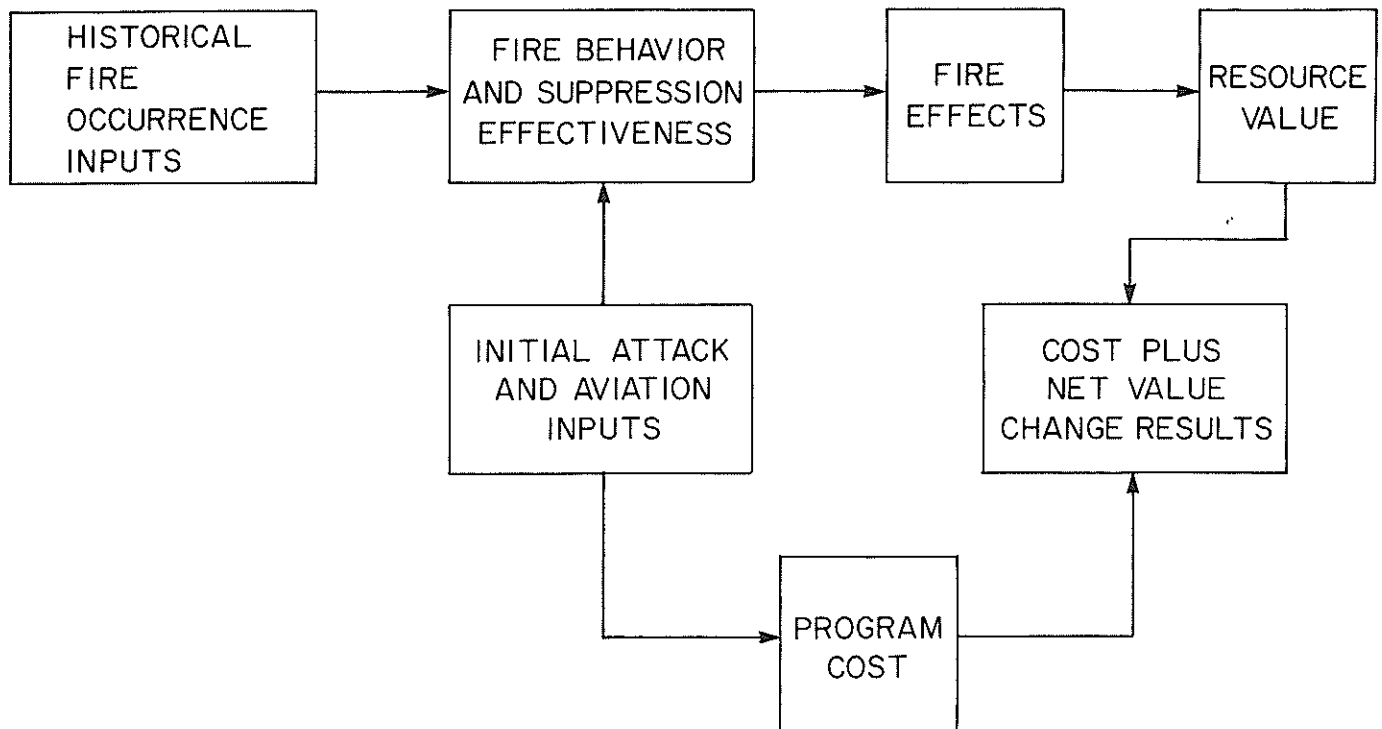


Figure 4—The model used in this six-Forest study includes these analysis components.

study. In 1979, the initial attack and aviation components accounted for \$95.4 million or almost three-fourths of the National Forest System fire management presuppression budget.

Case Study Forests

This study includes separate analysis of six National Forests: the Francis Marion on the coastal plain of South Carolina, the Huron-Manistee in the lower peninsula of Michigan, the Willamette on the western side of the Cascade Mountains in Oregon, the Deschutes on the eastern side of the Cascades in Oregon, the San Bernardino in southern California, and the Tonto in central Arizona. These Forests were selected because they could provide fire occurrence and road network information prepared in a manner compatible with the only reasonable fire management effectiveness model we could use. Coincidentally, they represent a broad range of fuels, topography, resources, and fire occurrence levels. Together, the six Forests accounted for about 12 percent of the Forest Service's initial attack and aviation appropriations in fiscal year 1979.

The analysis on each Forest progressed through six steps:

1. Determine the alternative initial attack and aviation program levels.
2. Compile the fire occurrence data for selected historical years.

3. Evaluate the effectiveness of the initial attack and aviation inputs.

4. Translate the estimates of numbers of fires by size and fire intensity into estimates of the effects upon resource outputs.

5. Calculate the value of those changes in resource output.

6. Compute the $C + NVC$ (fig. 4).

Initial Attack and Aviation Program Levels

The four budget or program levels (PL) for the initial attack forces evaluated were

- PL₁ 20 percent below the actual fiscal year 1979 appropriation
- PL₂ Fiscal year 1979 appropriation
- PL₃ 20 percent above the fiscal year 1979 appropriation. This approximated the fiscal year 1978 program level on average across the Forest Service.
- PL₄ 40 percent above the fiscal year 1979 appropriation

The general intent was to vary the budget for the aviation component of the fire management program by the same proportions. This constant proportional adjustment was not made in all Forests, however, as noted in the separate discussions. Therefore, the resulting initial

attack and aviation program levels are not always different by 20 percent increments.

The program levels studied were limited to this - 20 percent to + 40 percent range because of difficulties that would have been encountered in expert opinion gaming of large fire suppression effectiveness under more widely varying programs. The program level restriction was also based upon an initial hypothesis that the most efficient program lay within this broad budget range. One consequence of this program level restriction is that the program level which leads to the overall minimum C + NVC may not fall within the range tested.

Fire Severity Levels

Each of the initial attack and aviation programs was evaluated against the fires which occurred throughout an entire fire season. The random nature of fire occurrence and fire weather was recognized in the study by evaluating 3 separate historical years for each Forest—years which varied in their “fire year severity.” The fire starts in each of these years were identified by location on the Forest. The fire intensity and rate of spread were developed for each historical fire by a variety of methods using weather, fuel, and fire location records. Fire year severity was determined separately by each Forest but was generally based on the number of fire starts and the severity of the fire weather. The 3 fire years selected for analysis were given a relative rating of A, low; B, moderate; and C, high.

The objective of covering a full range of fire year severities was not fully met for several reasons. First, the case study Forests had a limited number of years of fire occurrence data stored in the format required for this analysis. The historical fire records which were available in the desired form were often for years of above average severity, at least when acres burned were used as an index of severity. Therefore, the 3 fire years chosen may not be assessed accurately with respect to all possible fire years. They are probably biased toward the high severity years.

Second, burning conditions vary within a year as well as between years. A year of average overall severity may contain a brief period of numerous fire starts and adverse fire weather which gives rise to large fires and very adverse fire effects. Judging severity by an entire year is therefore imprecise. Third, the potential fire effects are as much a function of the location of the fire as they are of the weather. Fire effects in a low severity year may therefore be more extensive when the fires occur near structures or in commercial timber than in a high severity year when the fires occur in light brush or grass.

It is essential to note that each of the 3 fire years is a unique historical array of fire locations, fire causes, and burning conditions. They are not, as in some studies, the same set of fires simulated under varying burning condi-

tions. The years chosen are not the same years for all six Forests.

Although the fire locations, fire numbers, and weather conditions were those peculiar to the actual year, the fuel and resource characteristics were not. For each Forest, the fuel loadings in place at the time of this study were used in the fire behavior module for all 3 fire severity years. Also, the interdisciplinary team which assessed fire effects assumed that the current resource conditions existed in all the simulated fire years.

The selection of varying fire year severities recognizes that the efficiency of a fire management program should not be evaluated against just one point on the distribution of fire year severities. By selecting several years, we are able to display some information on the range of possible consequences even though we did not analyze the full probability distribution of possible events. The number of acres burned on each Forest from 1958 to 1977 is shown in *table 1*.

Evaluating Fire Program Effectiveness

The FOCUS computer model was used to estimate the eventual size of each fire and to estimate the cost of the fire suppression activity (Bratten and others 1980). The fire start locations and the elapsed time between ignition and detection were determined from the historical records, and the location of the initial attack and aviation forces was set in each Forest. The initial attack and aviation forces were allocated to each fire based upon predetermined dispatching rules and model-calculated arrival times of different attack forces to the specific fire location. The productivity of the dispatched forces, expressed as the rate of fireline construction per hour, was then compared with the rate of fire perimeter growth to determine if the fire could be contained.

If this computer simulation showed that the fire burned to 100 acres or for more than 12 hours and was still not contained, the fire was identified as “escaped” and the computerized simulation of initial attack and aviation effectiveness was stopped. Beyond 100 acres or 12 hours, the fire behavior model assumptions about homogeneity in fuels, weather, and terrain are violated so much that the computerized modeling cannot be continued.

FOCUS model output for each escaped fire included the location, the character of the fire, and the amount of fireline built at the time of escape. With this information and the list of available initial attack and aviation inputs, fire specialists versed in the latest fire behavior technology studied each fire, defined the best suppression strategy, and then estimated the size the fire would reach when extinguished.

The fire suppression strategy used in the expert opinion gaming of large fires was consistent with the actual sup-

Table 1—Acreages burned in fires recorded on National Forests studied, 1958-1977¹

Year	Huron-Manistee	Willamette	Deschutes	Tonto	San Bernardino
1977	535	48	2,810	687	1,332
1976	1,678	280	4	24,053	1,889
1975	466	53	96	17,996	6,943
1974	446	155(B)	50	4,143(B)	14,937
1973	24	241	16	1,379	7,078(B)
1972	657	487	4	239(A)	2,860(A)
1971	168	430	21	707	52
1970	317	131(A)	59(A)	16,127(C)	64,320(C)
1969	93	126	450	12,352	1,529
1968	829(B) ²	49	1,823	5,167	7,991
1967	98(A)	12,815(C)	2,061(B)	1,722	259
1966	301(C)	338	16	23,808	2,476
1965	150	176	65	1,169	778
1964	269	9	93	7,387	16,237
1963	199	14	5	559	273
1962	152	142	155	464	1,710
1961	557	55	1,079(C)	3,563	1,036
1960	155	134	675	499	5,451
1959	16	181	14,301	30,838	18,733
1958	171	1,186	36	1,599	1,922

¹Data for Francis Marion National Forest are not shown here because such data were not available separately from other National Forests in South Carolina. On the Francis Marion, 1970 was chosen as Year B and 1968 was Year C.

²The letters in parentheses are the fire years simulated in this year.

pression strategy used in 1979 on those Forests. The revision of the fire management policy on National Forest lands occurred in 1978, but was not fully implemented in 1979.

The suppression cost for fires which were contained before reaching escape size or escape time was calculated internal to the FOCUS model from prespecified equipment and manpower costs. The suppression cost for escaped fires was calculated by hand using the same per unit costs.

The suppression costs were reported separately for three categories of inputs:

1. Forest Service primary inputs—firefighting program inputs generally financed from fire management presuppression appropriations.

2. Forest Service secondary inputs—the salary and equipment costs of Forest Service inputs, generally financed through nonfire program appropriations, which are temporarily diverted to fire suppression activities, such as timber stand improvement crews and road building equipment.

3. Cooperator inputs—the salary and equipment costs of other Federal, State, and private contractors who provide fire suppression inputs upon request.

The direct cost of using Forest Service suppression inputs which are shared between several forests, and the cost of

cooperator inputs, was charged to the case study Forests as suppression costs.

Secondary Forest Service inputs were assumed to be available when needed, but their response time was greater than for primary inputs. Cooperator inputs were assumed to be available at all program levels, but fewer were available during high fire severity years when demands for them would be greater elsewhere.

A secondary cost incurred when secondary Forest Service inputs are utilized, but not registered in this study, is the disruption of the activities to which crews and equipment are normally assigned, such as timber sale administration and road maintenance. While these inputs are assigned to fire suppression activities, their costs are paid by supplemental appropriations through the fighting forest fire (FFF) account, however, rather than from the budget for their originally assigned activities. Therefore, no budget reduction for the nonfire activities results from using secondary forces.

Fire Effects

Interdisciplinary teams of resource experts on each Forest estimated the fire effects upon resource outputs. Maps of the fires, estimates of fire size and intensity,

historical records of fire damages, and local knowledge of the Forest were the information available to the teams.

The interdisciplinary team estimated the fire effects for each fire greater than 100 acres. For fires 10 to 100 acres in size, effects were estimated using 10 sample fires from that size class, well distributed throughout the fire year. Results from the sample were then expanded to the entire set of fires in the size class as follows:

$$\left(\begin{array}{c} \text{Total value of fire} \\ \text{effects for} \\ 10\text{- to }100\text{-acre fires} \end{array} \right) = \left(\begin{array}{c} \text{Value of fire effects} \\ \text{on the sample fires} \end{array} \right) \times \left(\begin{array}{c} \text{Total acres burned in} \\ 10\text{- to }100\text{-acre fires} \\ \hline \text{Acres burned in} \\ \text{sample fires} \end{array} \right)$$

If less than 10 fires occurred in the 10- to 100-acre size class, effects were estimated for all of them.

The fire effects for 0- to 9-acre fires were estimated using an assumption that the per acre value of effects was the same as the average per acre effect for 10- to 100-acre fires by:

$$\left(\begin{array}{c} \text{Total value of fire} \\ \text{effects for} \\ 0\text{- to }9\text{-acre fires} \end{array} \right) = \left(\begin{array}{c} \text{Per acre value of} \\ \text{fire effects for} \\ 10\text{- to }100\text{-acre fires} \end{array} \right) \times \left(\begin{array}{c} \text{Total acres burned} \\ \text{in } 0\text{- to }9\text{-acre fires} \end{array} \right)$$

This may overestimate the detrimental effects of the 0- to 9-acre fires. Smaller fires are often less intense than larger fires and some detrimental effects, such as soil erosion, are positively correlated with fire size.

Fire effects were estimated for each of the resource categories shown in *table 2*. Only the net resource change for each category was recorded and valued. For example, the net effect on commercial timber output is the present value of the timber that would have been harvested in the absence of the fire minus the value of the burned timber salvaged. Potential second rotation timber harvests beyond the immediate postfire salvage harvest were not included in the net value calculations. This may have led to a larger-than-actual net detrimental change in the timber resource category.

The net fire effects could be either positive or negative. Much of the rangeland grazing, wildlife effects, and effect on usable water quantity, for example, were negative; yields were greater with the fire than without it. Effects on water storage capacity, on the other hand, were positive; the capacity was less with the fire than without it. Similarly, fire effects were only recorded if there was an actual change in resource outputs. Tree mortality in a wilderness area was not registered as a commercial timber effect, for example, because it would not have been harvested even if it had not burned. The tree mortality may have led to a change in recreation usage, however, which would have been included as a recreation effect. Again, negative numbers imply beneficial effects and positive numbers imply detrimental effects.

Direct offsite fire effects, such as downstream flooding and siltation, were included in the total effects estimate along with the direct fire-site effects. The only exception

to this offsite rule was in the San Bernardino Forest, where effects were measured off the fire site but not beyond the Forest boundary. Effects on resource outputs which extend into the future were also included. The present net worth of the future harvest of seedling and sapling and of poletimber stands was included for example rather than their current market value.

It was assumed that the effects upon commercial forage, water use, fish habitat, wildlife habitat, and recreation would occur for a period of up to 7 years. For discounting purposes, a simplifying assumption was made that those 7 years of effects all occurred during year 3. The simple sum of 7 years' effects was therefore multiplied by the per unit resource values and discounted 3 years to the present. Annual estimates of water volume loss due to the siltation of water storage facilities were derived for 25 years. A 10 percent discount rate was used.

Three fire effects were estimated by the interdisciplinary team but not valued in dollar terms. The first was effects upon unique resources such as historical and cultural sites, unique ecosystems, and endangered and threatened flora and fauna. The second was an estimate of the number of days that fires would cause air quality to fall below accepted standards. The third was the number of days when fires would cause water quality to deteriorate below accepted standards.

The only major direct fire effect excluded was the long-term effect on soil productivity sometimes caused by fire. No secondary impacts on the wages and employment in affected local economies was included.

Table 2—Resource categories for which net fire effects were estimated and subsequently valued

Resource category	Unit of measure
Commercial timber	
Sawtimber, hardwoods	Thousand board feet
Sawtimber, softwoods	
Poletimber stands	Acres
Seedling and sapling stands	
Commercial range	Animal unit months
Usable water	Acre-ft
Water storage capacity	Acre-ft
Fish habitat	
Warm water fish	User days
Cold water fish	
Anadromous fish	
Wildlife habitat	
Big game animals	User days
Other game animals	
Nonconsumptive uses	
Recreation	
Developed	User days
Dispersed	
Wilderness	
Structures	
Federal management	Number of units
Federal administrative	
Privately owned	
Miscellaneous	

It would have been desirable to have more comprehensive empirical data on which to base the fire effects estimates rather than to depend so greatly on the expert opinion of the interdisciplinary team. However, because the same team estimated the fire effects for each year and each program level on a given Forest, fire effects biases or errors most likely cancel out in a marginal analysis study like this one. In a marginal analysis, the incremental change in the fire effects between program levels, rather than the total fire effects, is the important quantity.

Resource Values

The fire effects upon resource outputs were valued using average regional per unit values. The values were marginal willingness-to-pay estimates, which include some consumer surplus as well as the revenue captured in a market transaction. The use of willingness-to-pay values permits uniform application of the same valuation concept across all resource categories. These values were preliminary estimates developed for the evaluation of alternative Forest Service programs defined in accordance with the Forest and Rangeland Renewable Resources Planning Act (*table 3*) (U.S. Dep. Agric., Forest Serv. 1978c). This provided consistency in the values used in the evaluation of all Forest Service programs and among resource categories. Fire effects upon structures were valued on the basis of their replacement cost.

Application of regional value averages to the respective case study Forests and the difficulty in deriving values for

the nonmarket commodities like recreation and wildlife led to less precise resource value estimates than initially desired. Especially when the difficulties of resource valuation were combined with those related to deriving fire effects from expert opinion, questions arose about the quality of the net value change estimate. The real question, however, is whether more accurate data in this phase of the analysis would affect the conclusions of the study. Some fairly simple sensitivity analysis for each Forest shed light on this.

All of the *table 3* values are current dollar values per unit of output with the exception of the commercial timber values for immature poletimber and seedling and sapling stands. The loss incurred from burning an immature timber stand is the value of the foregone harvest volume that the stand would have generated. This was calculated by compounding all future harvests to the end of the rotation. The immature timber values in *table 3* are the future values per acre at the time of harvest. Those future values were then discounted back to a stand age of zero. A more accurate calculation of foregone value per acre burned is the future net value at time of final harvest discounted back to the current stand age. The calculation we used underestimates the timber value loss from immature stands in this study but subsequent sensitivity analysis demonstrates that the error has no effect on the conclusions reached.

The poletimber stand regimes assume one commercial thinning and a final harvest. The seedling and sapling stands assume two potential commercial thinnings, because they are younger when burned, and a final

Table 3—Average dollar values per unit of resource output affected by fire for the National Forests studied

Resource Category	Output unit	Tonto	San Bernardino	Deschutes	Willamette	Francis Marion	Huron-Manistee
		<i>Dollars/unit</i>					
Commercial timber							
Mature, hardwood	MBF	0.00	0.00	0.00	0.00	34.00	44.00
Mature, softwood	MBF	84.00	131.00	166.00	166.00	107.00	37.00
Pole stands	Acres ¹	1,083.00	6,202.00	6,555.00	8,316.00	7,303.00	742.00
Seedlings-saplings	Acres ¹	8,040.00	70,367.00	24,964.00	19,522.00	54,218.00	1,362.00
Commercial range	AUM	3.90	3.30	3.00	3.00	2.45	3.35
Water use	Acre-ft	0.50	2.60	1.50	1.50	1.50	1.00
Water storage	Acre-ft	0.50	2.60	1.50	1.50	1.50	1.00
Fish habitat							
Warm water	User days	4.25	4.25	4.25	4.25	4.25	4.25
Cold water	User days	6.25	6.25	6.25	6.25	6.25	6.25
Anadromous	User days	—	19.50	19.50	19.50	—	19.50
Wildlife habitat							
Big game	User days	10.50	10.50	10.50	10.50	10.50	10.50
Other game	User days	8.00	8.00	8.00	8.00	8.00	8.00
Recreation resources							
Nonconsumptive	User days	7.25	7.25	7.25	7.25	7.25	7.25
Developed	User days	3.00	3.00	3.00	3.00	3.00	3.00
Dispersed	User days	3.00	5.50	3.00	3.00	5.50	5.50
Wilderness	User days	8.00	10.00	10.00	10.00	15.00	14.00

¹Per acre net future value at time of final harvest.

harvest. The compounded value of that first commercial thinning is the reason for the larger seedling and sapling net future value at maturity than for the poletimber stands.

The results for each Forest are presented separately. Information is provided on the initial attack and aviation program levels tested, the C + NVC results, suppression costs, and net value change in resource outputs and structures. The case studies should be read in the order they are presented since complexities of analysis are discussed as they are encountered.

FRANCIS MARION NATIONAL FOREST

The Francis Marion National Forest, located in South Carolina, is typical of the coastal plain forests of the Southwest. The area is well drained by numerous, slow-moving streams. Southern pines are the predominant woody vegetation, but hardwoods dominate in areas where fire or some other ecosystem modifier, such as timber harvesting, has not retarded the progression toward climax vegetation.

The Francis Marion is the smallest Forest in the study, covering 249,000 acres (U.S. Dep. Agric., Forest Serv. 1979a). Although ownership within the Forest boundary is mixed, 60 percent of the acreage is National Forest ownership. On average, 40,000 acres are burned by prescription each year to meet various resource management and hazard reduction objectives.

The fire season generally extends from April to late October. In most years, relatively short periods of severe burning conditions in the spring and late fall are separated by moist midsummer conditions.

Fire Years

Only 2 fire years were simulated in this case study Forest. Of the 6 years of fire occurrence data stored in a

FOCUS-compatible form, 5 years were essentially the same. One of these five was designated Year B (relatively moderate), and the sixth was designated Year C, relatively high. (See *tables 1* and *4*, for a comparison of fire years among the Forests.) There was a total of 87 fires in Year B and 133 fires in Year C. There were 0.35 fires per thousand acres of Forest acreage in Year B and 0.53 fires per thousand acres in Year C.

Program Levels Tested

The initial attack program levels tested ranged from \$46,000 at PL₁ to \$80,000 at PL₄ (*table 5*). No aviation program was included in the Francis Marion fire management program. The initial attack cost at the PL₂ level was \$0.23 per acre within the Forest boundary (*table 6*). Recall that the program level is only part of the presuppression budget for the Forest. The fuel treatment, fire prevention, and detection program components are not included.

Economic Efficiency Results

The initial attack program level with the lowest C + NVC in Year B was PL₁. PL₁ was therefore the most economically efficient program, based upon the inputs evaluated in this study and the value of resource outputs included in this study (*table 5*). Since PL₁ was the smallest program tested, the overall minimum C + NVC could occur at a program level below PL₁. The \$10,000 difference in C + NVC between PL₂ and PL₁ is the estimated increase in the present net worth for each year that the initial attack program is reduced from PL₂ to PL₁.

The major determinant of the Year B minimum C + NVC was the change in the initial attack program input level itself. The net value change was small relative to the total C + NVC, and it changed very little from one program level to the next. The suppression cost was a larger percentage of the total C + NVC than the net

Table 4—The number of fire starts by fire year and by National Forest

National Forest	Number of fires			Fire starts per thousand acres ¹		
	Year A	Year B	Year C	Year A	Year B	Year C
Francis Marion	—	87	133	—	0.35	0.53
Huron-Manistee	47	116	146	0.051	0.13	0.16
Deschutes	403	238	340	0.25	0.15	0.21
Willamette	363	237	432	0.22	0.14	0.26
San Bernardino	377	364	499	0.60	0.58	0.79
Tonto	251	278	262	0.09	0.10	0.09

¹The acreage includes all National Forest land within the respective Forest boundary.

Table 5—Economic efficiency of fire management program levels as measured by cost plus net value change (C + NVC), Francis Marion National Forest

Fire severity year and initial attack program level	Components of C + NVC			Total C + NVC	Quality standards violations		Simulated area burned
	Initial attack forces budget ¹	Suppression cost	Net value change in resources ²		Air	Water	
	Thousand dollars				Days		Acres
B:							
PL ₁	46	13	-1	458	44	0	920
PL ₂	57	11	3	68	44	0	898
PL ₃	68	10	3	78	44	0	812
PL ₄	80	8	3	88	44	0	648
C:							
PL ₁	46	37	-3	480	50	0	2,344
PL ₂	57	29	-2	84	18	0	1,978
PL ₃	68	27	-2	93	18	0	1,920
PL ₄	80	25	-2	103	18	0	1,761

¹No aviation operation was included in the program for this Forest.

²Net value change is negative for net beneficial fires (resource outputs greater "with" the fires than "without"), and positive for net detrimental fires. There were no effects on unique resources at any level for any year tested.

³Less than \$0.5 thousand.

⁴Program level with lowest C + NVC; therefore most economically efficient of those tested for that severity year.

Table 6—Cost of fire management program components studied, in fire year B, at program level 2, by National Forest

National Forest	Initial attack and aviation	Suppression
	Dollars per acre ¹	Dollars per acre burned
Francis Marion	0.23	12
Huron-Manistee	0.15	19
Deschutes	0.66	3651
Willamette	0.64	2043
San Bernardino	11.77	99
Tonto	0.51	166

¹The acreage includes only National Forest land within the respective Forest boundary.

value change, but it too changed little by program level. These patterns are quite clear in the C + NVC bar graphs in figure 5. In a marginal analysis, the most efficient program level, and therefore the location of the minimum C + NVC point, is controlled by what changes from one PL to the next and not the absolute magnitude of the components at any one program level. Even a large contributor to the total C + NVC does not affect the location of the C + NVC minimum if it is relatively constant across program levels.

The most efficient program in the more severe Year C was also PL₁, the lowest program level tested. A smaller present net worth increase was achieved in moving from PL₂ down to PL₁ in the relatively high severity year (C) (\$4000) than in the moderate year (B). The increase in fire year severity still did not lead to an increase in the size of

the most efficient program, however. This was true in spite of the estimate that almost two and a half times as many acres burned in Year C (2344 acres) at PL₁ than in Year B at the same program level (920 acres).

Again, the relevant question is not just how many acres burn but how much fires affect the value of resource outputs, and whether that change in the value of resource outputs resulting from fire can be affected by the size of the initial attack program. In the Francis Marion case study, the fires caused very little net value change and even that small amount was not affected by program size above PL₂ in either year tested.

Suppression Costs

The Francis Marion suppression costs in Year B were a relatively small percent of the total C + NVC, 23 percent at PL₁. The suppression cost per acre burned was also relatively low, \$12/acre. This was the lowest suppression cost per acre burned of any of the Forests studied when Year B and PL₂ is used as the point for comparison.

Suppression costs per acre burned are not an index of economic efficiency. Low costs per acre burned are not inherently more efficient than high costs. Lower costs may simply result from larger fires. The suppression costs per acre burned do provide a rough indication, however, of the relative suppression program intensity between Forests.

One reason that suppression costs were low on the Francis Marion was that the fuel loadings were relatively

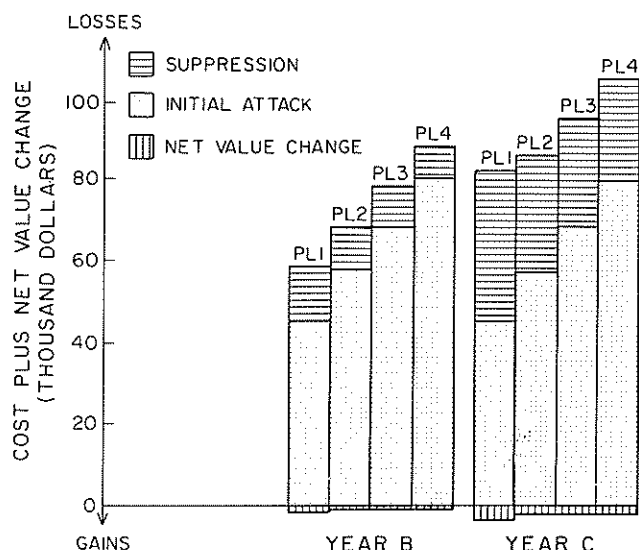


Figure 5—Determinants of minimum cost plus net value change are evident in the chart for the Francis Marion National Forest. (The program for this Forest did not include aviation.)

low as a result of their 30-year history of prescribed fire. The current prescribed burning program on the Forest costs \$100,000 annually, which is twice the cost of the initial attack program. Prescribed fire has been used primarily as a silvicultural tool for timber production and to enhance other resources such as wildlife habitat, but a side benefit is an easier fire suppression job. In addition to the prescribed fire history, the gentle terrain and easy access to most points on the Forest contributed to low suppression costs.

On the premise that at least one well-trained fire specialist be available on the Forest during the fire season, the initial attack budget at PL₁ (\$46,000) cannot be reduced indefinitely. The minimum may be as small as one-half a year's salary for the fire specialists plus transportation and equipment, however, if secondary forces are available for suppression actions. It is noteworthy, though, that secondary forces were not needed on the Francis Marion in the simulated fire years.

Resource Value Change

A striking feature of the net value change estimates in both simulated years was that, on net, all of them were beneficial changes. The fires resulted in more resource output than would have occurred in the absence of fire.

The net value changes at PL₂ were as follows:

Resource category:	Year B	Year C
Usable water	\$ 43	\$ 166
Wildlife habitat	408	1,867
Total	\$451	\$2,033

These are among the same resource outputs that are enhanced by the prescribed burning program.

The fires had no impact upon unique resources and did not lead to any violations of water quality standards. There were 44 days of air quality standards violated in Year B, but the number of days did not change at different program levels. In Year C, 50 days of air quality standards were violated at PL₁. This dropped to 18 days at levels PL₂ to PL₄.

If we assume that the air quality violation was the only impact excluded from the economic efficiency calculations, we can calculate the minimum opportunity cost for a day's violation in Year C. The change between PL₁ and PL₂ was \$4000 in C + NVC and 32 days of violation. Therefore, if it is worth at least \$125 (\$4000/32 days) to prevent a day of air quality standard violation, PL₂ was the most efficient program level in Year C.

These estimates from the 2 years studied on the Francis Marion do not imply that detrimental fires never occur. For example, fires sometimes kill the seedlings in the pine plantations that were established for timber production. Particularly adverse fire weather, fuel, terrain, and fire ignition conditions on the Francis Marion certainly would lead to detrimental changes in resource outputs. The simulation of 220 fires in this study did not result in any detrimental fires, however.

Another striking feature of the Francis Marion net value change estimates is that they are a very small percent of the total C + NVC, reaching a maximum of 4 percent in Year C at PL₁. This minor contribution to C + NVC and the minor changes in net value change between program levels indicates that the fire effects and the per unit resource values used would have to be in substantial error before the location of the most efficient program level would change.

HURON-MANISTEE NATIONAL FOREST

This Forest of 923,000 acres is located in the northern half of the lower peninsula of Michigan. Hardwoods are the predominant vegetation but intermixed conifer stands of mostly jack pine and red pine are common. The topography is gentle, varying from flat to rolling hills as a result of the past glaciation. The land is well drained and contains numerous inland lakes. The lakes support a large native fish population and some of the rivers contain anadromous fish from Lake Michigan.

A significant portion of the Forest is composed of reforested farmland abandoned in the early 1900's. As a result, small communities are common within and adjacent to the Forest. Only 45 percent of the acreage within the Forest boundary is National Forest ownership, a smaller percentage than for any of the six Forests.

Table 7—Economic efficiency of fire management program levels as measured by cost plus net value change (C + NVC), Huron-Manistee National Forest

Fire severity year and initial attack program level	Components of C + NVC			Total C + NVC	Quality standards violations		Simulated area burned
	Initial attack forces budget ¹	Suppression cost	Net value change in resources ²		Air	Water	
	Thousand dollars				Days		Acres
A:							
PL ₁	110	5	-1	⁴ 114	0	0	323
PL ₂	138	6	-1	143	0	0	307
PL ₃	166	6	-1	171	0	0	307
PL ₄	193	6	-1	198	0	0	292
B:							
PL ₁	110	18	-10	⁴ 118	0	0	1,030
PL ₂	138	17	-6	149	0	0	890
PL ₃	166	17	-5	178	0	0	839
PL ₄	193	18	-2	209	0	0	792
C:							
PL ₁	110	19	9	⁴ 138	0	0	1,646
PL ₂	138	19	6	163	0	0	1,292
PL ₃	166	18	6	190	0	0	1,246
PL ₄	193	16	7	216	0	0	1,236

¹No aviation operation was included in the program for this Forest.

²Net value change is negative for net beneficial fires (resource outputs greater "with" the fires than "without"), and positive for net detrimental fires. There were no effects on unique resources at any level for any year tested.

³Less than \$0.5 thousand.

⁴Program level with lowest C + NVC; therefore most economically efficient of those tested for that severity year.

The fire season normally extends from mid-April to mid-August with an additional period in the month of October. Summer weather is often damp and moderately humid, but selected years may include drought periods in the spring, summer, and fall, leading to higher fire severity.

Fire Years

Year B had 116 fires, a fire density of 0.13 fires per thousand acres of Forest ownership. This is similar to the fire density for Year B on the Willamette, Deschutes, and Tonto National Forests.

Program Levels Tested

The initial attack program levels tested on the Huron-Manistee varied from \$110,000 at PL₁ to \$193,000 at PL₄ (table 7). As on the Francis Marion, there was no aviation component in the fire management program on the Huron-Manistee. The initial attack cost at PL₂ was \$0.15 per acre, the lowest of the six Forests.

Economic Efficiency Results

The most economically efficient program level on the Huron-Manistee in Year B was PL₁, just as it was on the Francis Marion. The increase in program present net worth achieved by the reduction from PL₂ to PL₁ in Year B was \$31,000. PL₁ was also the most efficient program of those tested in Year A and Year C.

The major determinant of the most efficient program was the change in the initial attack program level (fig. 6). The net value change and suppression costs were again a small percentage of the total C + NVC, and they changed very little in response to initial attack program level changes.

Suppression Costs

The suppression cost in Year B at PL₂ was \$17,000 for the year. This was 11 percent of the total C + NVC. Suppression costs were fairly constant from one program level to the next, showing no significant decline as the initial attack program size was increased.

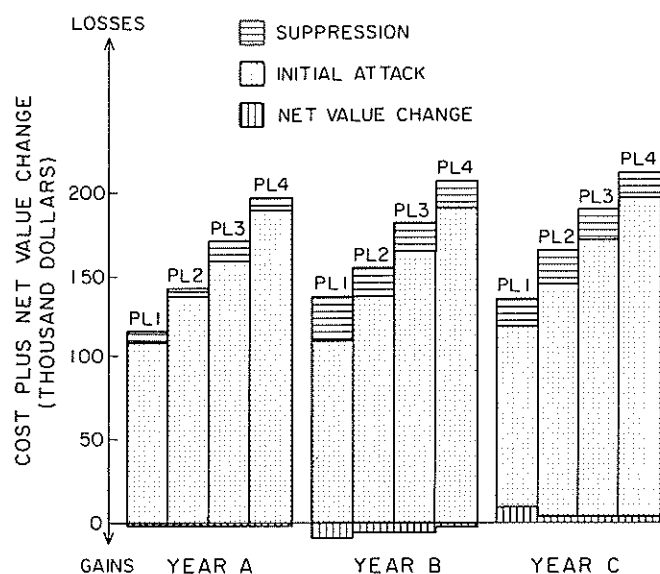


Figure 6—Determinants of minimum cost plus net value change are evident in the chart for the Huron-Manistee National Forest. (The program for this Forest did not include aviation.)

Table 8—Net value change on the Huron-Manistee National Forest by fire year, resource category, and program level (PL₁ lowest)

Fire year and resource category	Net change ¹			
	PL ₁	PL ₂	PL ₃	PL ₄
<i>Thousand dollars</i>				
A:				
Commercial timber	3	3	3	3
Wildlife habitat	-4	-4	-4	-3
Total	-1	-1	-1	0
B:				
Commercial timber	3	5	5	4
Wildlife habitat	-13	-11	-11	-6
Total	-10	-6	-6	-2
C:				
Commercial timber	6	3	2	2
Wildlife habitat	2	2	2	2
Recreation	1	2	2	2
Structures	5	4	4	4
Total	9	7	6	7

¹Columns may not add due to rounding.

²Less than \$0.5 thousand.

Almost all of the fires were less than 100 acres in size. In Year C, 3 fires out of 146 exceeded 100 acres at PL₁. This was the greatest number to exceed 100 acres in any year or program level of those simulated on the Huron-Manistee. The number of fires in the 10- to 100-acre size class was also almost constant from one program level to the next. This fire size distribution and its consistency from one program level to another helps explain why suppression costs were relatively low and constant.

The per acre suppression costs on the Huron-Manistee were relatively low, \$19 per acre, lower than any other of the case Forests except the Francis Marion. Because the Huron-Manistee has a relatively low biomass productivity, fuels have accumulated slowly since the land was removed from agricultural use. The gentle topography and ready access, and assistance by Forest visitors in the rapid detection and suppression of fires, helped to keep suppression costs low as did the generally low fuel loadings.

All fires were suppressed by primary Forest Service fire management personnel supported by the initial attack budget. The low initial attack budget on the Huron-Manistee led to 20 "no dispatch" fires in Year C at PL₁ and 9 "no dispatch" fires in Year C at higher program levels. A "no dispatch" fire is identified in FOCUS model output when all initial attack forces which are identified as available for fire suppression have already been dispatched to an existing fire. The fire then spreads naturally until attack forces are free. Because of the small initial attack program level, if a large number of fires started near the numerous private structures interspersed throughout the Forest, substantial damage could occur. This did not happen in the simulated years. Some structural losses occurred in Year C, but the losses were lower than they might be.

Resource Value Change

The net change in the value of resource outputs was a very small percentage of the total C + NVC, reaching a maximum of 9 percent in Year B at PL₁. Like those on the Francis Marion, the fires tested on the Huron-Manistee in Year A and Year B in net were beneficial. The increased value of wildlife output which resulted from the fires outweighed the detrimental impact upon commercial timber output (table 8).

The net value change in Year C was detrimental. Wildlife habitat benefits resulting from the Year C fires were small. Detrimental effects were estimated in commercial timber, recreation, and in the loss of structures. This predominance of commercial timber and structural losses relative to the other resource categories was repeated throughout many of the other case study Forests.

All of the fires over 100 acres were started when debris-burning fires escaped due to strong winds. All of these occurred during wet periods in the fall of the year. No net value changes were recorded, either positive or negative, for those fires. No air or water quality standards were violated as a result of the fires, and no unique resources were affected.

Questions about the accuracy of the fire effects and regional average resource value data arose here too. For example, the Resources Planning Act average regional values for commercial timber used in this study are over three times as high as the actual average stumpage price of timber sold on the Huron-Manistee in fiscal year 1978. Just as in the Francis Marion case, however, the relevant question is whether the data errors change the results. Given the relatively small contribution of net value changes to the total C + NVC, and its relative constancy from one program level to the next, the reduction of the estimated commercial timber stumpage prices by two-thirds would not change the minimum C + NVC location, nor would reasonable changes in the other resource effects or values do so.

Selection of Fire Year for Simulation

The historical fire years were selected on the basis of their relative severity. Since many factors influence the actual burned area, the simulated acres burned may not coincide exactly with the actual burned area (*table 1*). Equally important, the selected years are simply three points on the full distribution of potential fire year severity. Years more severe than Year C and less severe than Year A have occurred in the past and may occur in the future.

The Mack Lake fire in 1980 on the Huron-Manistee burned 24,790 acres and several structures. This fire points up the hazard of using too few points on the probability distribution of fire year severity or of failing to remember that Year C is not the most severe year possible. In the relatively infrequent years when fire severity is very high, the almost continuous poletimber stands of jack and red pine can, and have, led to large, detrimental fires. Although it is very difficult to determine the probability of occurrence of those infrequent severe events, their possibility should not be ignored.

Table 9—Economic efficiency of fire management program levels as measured by cost plus net value change (C + NVC), Deschutes National Forest

Fire severity year and initial attack program level	Components of C + NVC			Total C + NVC	Quality standards violations		Simulated area burned
	Initial attack forces budget ¹	Suppression cost	Net value change in resources ²		Air	Water	
	Thousand dollars				Days		Acres
A:							
PL ₁	533	460	60	41,348	0	0	282
PL ₂	688	421	46	1,517	0	0	249
PL ₃	899	187	41	1,489	0	0	234
PL ₄	1,181	191	37	1,763	0	0	226
B:							
PL ₁	532	303	65	41,196	0	0	129
PL ₂	688	303	41	1,394	0	0	83
PL ₃	899	132	33	1,426	0	0	65
PL ₄	1,181	104	28	1,667	0	0	57
C:							
PL ₁	532	743	323	41,894	5	0	964
PL ₂	688	730	267	2,047	5	0	901
PL ₃	899	400	265	1,926	5	0	864
PL ₄	1,181	440	277	2,252	5	0	865

¹No aviation operation was included in the program for this Forest.

²Net value change is negative for net beneficial fires (resource outputs greater "with" the fires than "without"), and positive for net detrimental fires. There were no effects on unique resources at any level for any year tested.

³Less than \$0.5 thousand.

⁴Program level with lowest C + NVC; therefore most economically efficient of those tested for that severity year.

DESCHUTES NATIONAL FOREST

The Deschutes is located on the eastern slope of the Cascade Mountains in central Oregon. The topography is generally mountainous and the wide range of elevations on the Forest results in ecosystems which range from semiarid high desert to alpine forest. Ponderosa pine is the major commercial tree species throughout the Forest. Resident and anadromous fish are found on the Forest, and big game hunting is a major activity.

The Forest covers 1,603,000 acres. In sharp contrast to the two eastern Forests, most of the acreage within the Deschutes boundary (87 percent) is National Forest land. There are a few small towns on the edge of the Forest. The fire season usually extends from May through November. Unlike the relatively wet summers in the two eastern Forests, the summers here are usually quite dry and dry thunderstorms are common.

The number of fire starts in Year B was 238. The fire start density on National Forest land in Year B was 0.15 fires per thousand acres.

Program Levels Tested

The initial attack and aviation program level tested varied from \$828,000 to \$1,535,000 (table 9). The initial attack and aviation cost was \$0.66 per acre at PL₂, con-

siderably higher than the \$0.23 for the Francis Marion and \$0.15 for the Huron-Manistee.

One result of the separate line item appropriations for initial attack and aviation operations in the 1979 budget was that the fiscal year 1979 initial attack and aviation program balance was not efficient. At PL₂, the program was too heavily weighted toward aviation. Therefore, instead of varying initial attack alone by ± 20 percent increments in the simulation, the entire initial attack and aviation program level was changed by approximately ± 20 percent increments. The aviation program was reduced in PL₁. It was held at about the same level in PL₃ and PL₄ as it was in PL₂. The initial attack component was increased greatly in PL₃ and PL₄ to bring it into a more efficient balance with aviation inputs.

The imbalance toward aviation was retained in the PL₂ starting point, however, since it was dictated by the 1979 budget. The impact of this imbalance can be seen in the suppression cost estimates which were heavily influenced by the extensive use of high cost aircraft on initial attack.

Economic Efficiency Results

The program level with the least C + NVC in Year B in the Deschutes case study was PL₁ just as it was in the Francis Marion and the Huron-Manistee (fig. 7). The majority of the C + NVC was again composed of the initial attack and aviation program input with a smaller portion of suppression costs and a very small portion of net value change in resource outputs and structures. The most efficient program level in Years A and C was also PL₁. The severity of the fire year again influenced the suppression and net value change but not by enough to change the most efficient program level.

In contrast to the trend shown for the two Forests discussed earlier, there was no smooth C + NVC transition from PL₄ to PL₁. The C + NVC of PL₃ is less than that for PL₂ in Year A and Year C, and the two C + NVC's are very close in Year B. The initial attack and aviation imbalance and its impact upon suppression costs caused this. The relative overabundance of aviation inputs in PL₁ and PL₂ led to a higher use of relatively expensive aircraft simply because they were available. A more appropriate initial attack and aviation program mix would reduce the PL₁ and PL₂ suppression costs below those simulated here and probably also reduce the total C + NVC in turn.

This change in the initial attack and aviation program composition across the four program levels tested, and the impact it had on C + NVC, points out that a family of C + NVC curves actually exists, one for each program composition or mix (Mills 1980). The discontinuity of the C + NVC results on the Deschutes illustrates the hazard of trying to find the minimum C + NVC by changing program mixes and program levels simultaneously. A more certain way to locate the overall

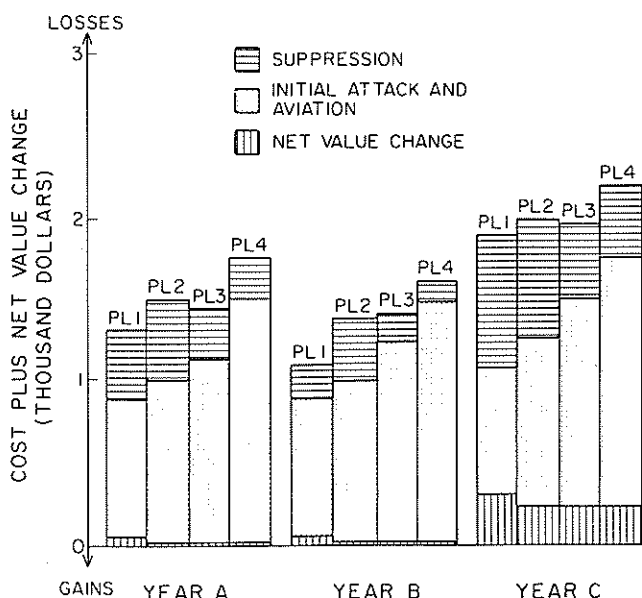


Figure 7—Determinants of minimum cost plus net value change are evident in the chart for the Deschutes National Forest.

C + NVC minimum is to trace the entire family of C + NVC curves by holding the program mixes constant one at a time while a range of program levels is evaluated. The program mix should then be changed and the program levels incremented again. The overall frontier of C + NVC minimum points can then be derived from the family of C + NVC curves and the overall minimum can be located on that frontier.

Suppression Costs

The cost of suppression in Year B at PL₂ was \$303,000, 22 percent of the C + NVC. The PL₁ and PL₂ suppression costs were similar in all 3 simulated years and the same was true of the PL₃ and PL₄ suppression costs (fig. 7), again because of the program imbalance.

Very few fires reached a size greater than 100 acres—one in Year A and one in Year C. The greatest number exceeding even 10 acres was five in Year C at PL₁. This small size distribution, in combination with the terrain and access characteristics which required use of aircraft for rapid initial attack, led to an average suppression cost in Year B at PL₂ of \$3651 per acre burned. The corresponding cost in Year A was \$1691 per acre, and Year C was \$810 per acre. This suppression cost per acre burned was roughly 10 times as large as the cost in the two eastern Forests.

It is again important to note that suppression costs per acre burned are not a reliable measure of economic efficiency. The C + NVC minimization is the proper indicator for that. The per acre suppression costs and the relation between suppression costs and net value changes do provide some hints, however, about whether alternative fire suppression strategies should be investigated. In Year B at PL₂, for example, the \$3651 per acre suppression cost occurred coincidentally with a net value change of \$494 per acre burned. It *cannot* be concluded from this that suppression is too aggressive. The acres burned and net value change could increase substantially under a less aggressive, and perhaps less costly, suppression strategy. The ratio of suppression to net value change does indicate, however, that alternative suppression strategies should be evaluated.

The bulk of the suppression cost on the Deschutes was primary Forest Service fire inputs in Year A and Year B. In Year C, a heavier portion came from secondary inputs. Cooperator inputs were small in all fire years. The suppression costs at PL₂ by year are as follows:

	Year A	Year B	Year C
Source:	----- Thousand dollars -----		
Primary Forest Service	\$368	\$261	\$406
Secondary Forest Service	50	40	321
Cooperator	3	2	3
Total	\$421	\$303	\$730

Resource Value Change

The net value changes in Years A and B were a small percentage of the total C + NVC. The highest in Year B was 5 percent when the net value change reached \$65,000 at PL₁. The net value change estimated in Year C was quite a bit higher, reaching \$323,000 at PL₁. This was 17 percent of the total C + NVC. Year C on the Deschutes was the first time in the three case studies described so far where the net value change exceeded 5 percent of the total C + NVC.

Almost all of the net value change on the Deschutes was damage to commercial timber (table 10). The \$166 per thousand board feet timber value used in this study was 40 percent lower than the fiscal year 1978 stumpage price received on the Deschutes, so the net value changes were underestimated. An increase in the stumpage price would lead to a proportional net value change increase. Because the net value change is relatively constant here across program levels, however, the increase would not affect the selection of the most efficient program level.

No fire-related water quality standard violations were reported on the Deschutes, and no unique resources were affected. Air quality standards were violated in Year C (5 days), but the number of days affected was not sensitive to the level of initial attack and aviation program.

Table 10—Net value change on the Deschutes National Forest by fire year, resource category, and program level (PL₁ lowest)

Fire year and resource category	Net change ¹			
	PL ₁	PL ₂	PL ₃	PL ₄
Thousand dollars				
A:				
Commercial timber	60	46	41	37
Commercial forage	.. ²	.. ²	.. ²	.. ²
Water use	-1	-1	.. ²	.. ²
Water storage	2	2	2	2
Structures	1	1	—	—
Total	60	46	41	37
B:				
Commercial timber	65	41	33	28
Commercial forage	.. ²	—	—	—
Water use	.. ²	.. ²	.. ²	.. ²
Total	65	41	33	28
C:				
Commercial timber	323	264	262	275
Water use	.. ²	.. ²	.. ²	.. ²
Water storage	.. ²	.. ²	.. ²	.. ²
Wildlife habitat	.. ²	1	1	1
Recreation	2	2	2	2
Structures	2	2	2	1
Total	323	267	265	277

¹Columns may not add due to rounding.

²Less than \$0.5 thousand.

WILLAMETTE NATIONAL FOREST

The Willamette is on the western slope of the Cascade Mountains in the Douglas-fir region of Oregon. Although the Willamette is adjacent to the Deschutes National Forest, the higher rainfall on the western slope has led to more productive timber stands, particularly at lower elevations. The timber species include old-growth Douglas-fir and other commercially valuable softwoods. Slopes are steep and well drained. Most of the streams contain spawning and rearing areas for salmon, steelhead, and other sea-run trout.

Because of the highly productive ecosystem and the relatively slow rate of decay, fuel volumes are very high. Fog and summer rain moderate burning conditions in most years, but during dry years, the heavy fuel loadings and steep terrain create a difficult fire control situation. Fire damage during these dry years is often high because of the commercial timber losses. Fire is used as a management tool to reduce fuel loadings following timber harvest.

This Forest covers 1,675,000 acres, almost the same amount as the Deschutes, and 93 percent of the land within the Forest boundary is National Forest land.

Year B had 237 fires, a fire density of 0.14 fires per thousand acres, almost identical to the number on the Huron-Manistee and the Deschutes.

Program Levels Tested

The initial attack and aviation program levels tested varied from \$931,000 at PL₁ to \$1,492,000 at PL₄. The initial attack and aviation program at PL₂ cost \$0.64 per acre, almost identical to the Deschutes and higher than the two eastern Forests.

Because of an imbalance between initial attack and aviation in PL₂, the total PL₁ level was not 20 percent below PL₂. The initial attack program was reduced 20 percent but the aviation component was only reduced 4 percent, so the total was only 13 percent lower. The PL₃ and PL₄ levels were approximately 20 and 40 percent above PL₂. The PL₂ program was 58 percent initial attack and 42 percent aviation. This was slightly heavier toward the aviation component than on the Deschutes where aviation was 35 percent of the initial attack and aviation program at PL₂. The aviation program was a heavier component of the initial attack and aviation program on these two Pacific Northwest Forests than on any of the other four case study Forests.

Economic Efficiency Results

The most efficient program level in Year B was PL₁, the lowest program level tested (*table 11*). Reduction in suppression cost and net value changes as initial attack

Table 11—Economic efficiency of fire management program levels as measured by cost plus net value change (C + NVC).
Willamette National Forest

Fire severity year and initial attack program level	Components of C + NVC			Total C + NVC	Quality standards violations		Simulated area burned
	Initial attack forces budget ¹	Suppression cost	Net value change in resources ²		Air	Water	
	Thousand dollars				Days		Acres
A:							
PL ₁	493	800	300	⁴ 2,031	0	0	268
PL ₂	618	779	295	2,146	0	0	263
PL ₃	769	582	252	2,117	0	0	225
PL ₄	948	584	237	2,313	0	0	187
B:							
PL ₁	493	562	158	⁴ 1,651	0	0	266
PL ₂	618	529	154	1,755	0	0	259
PL ₃	769	406	88	1,777	0	0	188
PL ₄	948	311	74	1,877	0	0	140
C:							
PL ₁	493	4,468	3,503	8,902	37	50	3,312
PL ₂	618	4,142	3,385	8,599	37	50	3,133
PL ₃	769	3,737	3,217	8,237	37	50	2,954
PL ₄	948	2,568	1,981	⁴ 6,041	32	20	1,730

¹No aviation operation was included in the program for this Forest.

²Net value change is negative for net beneficial fires (resource outputs greater "with" the fires than "without"), and positive for net detrimental fires. There were no effects on unique resources at any level for any year tested.

³Less than \$0.5 thousand.

⁴Program level with lowest C + NVC; therefore most economically efficient of those tested for that severity year.

and aviation program levels increased was not enough to offset the increased initial attack and aviation program input cost. The total $C + NVC$ in PL_1 of Year B was 56 percent initial attack and aviation input costs, 34 percent suppression costs, and 10 percent net value changes (fig. 8). This was a relatively lower percentage contribution of initial attack and aviation and a higher contribution of suppression costs than in the three Forests previously discussed.

PL_1 was also the most efficient program level in Year A, although there was little difference between the $C + NVC$ of PL_1 , PL_2 , and PL_3 . The initial attack and aviation contribution was an even smaller percentage of the total in Year A than in Year B, because both the suppression costs and the net value change contributions were greater. This relation existed because the years tested are actual historical years, each containing unique fire start locations. The delineation of actual fire year severity contains many factors of varying weight. These factors were only approximated here.

In Year C, PL_4 was the most efficient program level. This is the first Forest of the four so far described where some program level other than PL_1 was most economically efficient. It is also the first where the most efficient initial attack and aviation program level was influenced by the severity of the fire year. The $C + NVC$ was lower in Year C at PL_4 because both the suppression cost and net value change were much reduced, either one being more than sufficient to offset the \$209,000 increase in initial attack and aviation program cost between PL_3 and PL_4 .

A major cause of these results was the impact that initial attack and aviation increments had on the number of acres burned, especially in fires over 100 acres. The number of acres burned at PL_1 , PL_2 , and PL_3 was 2206

acres. From PL_3 to PL_4 , the burned area dropped from 2206 to 1006 acres.

It is not possible to determine in advance when a severe fire year will occur, at least not far enough to permit substantial change in the initial attack and aviation program. In Forests such as the Willamette, where fire season severity influences the most economically efficient program level, the single most efficient level for the long run must be determined by weighting $C + NVC$ results in each of various years by the probability that the year will occur in the future.

The expected value $C + NVC$ of any given program level across time is derived by

$$C + NVC_{Exp} = (C + NVC_A)(P_A) + (C + NVC_B)(P_B) + (C + NVC_C)(P_C)$$

where

$C + NVC_{Exp}$ = the expected value $C + NVC$ at the given PL

$C + NVC_A$ = $C + NVC$ for Year A at the given PL

P_A = probability of Year A occurring in the future

For example, the expected value $C + NVC$ in thousand dollars for the PL_1 level assuming a 0.025 probability for Year C and assuming a probability for Years A and B of 0.4875, is

$$\$2020 = (2,036)(0.4875) + (1,651)(0.4875) + (8,902)(0.0250)$$

At these same assumed probabilities, the expected value $C + NVC$ of PL_2 , PL_3 , and PL_4 is all higher than the $C + NVC$ of PL_1 (table 12). Therefore, if the Year C probability is 0.025—or stated another way, if Year C occurs once every 40 years—it would be more efficient to sustain greater losses and higher suppression costs in that severe year than to provide greater initial attack and aviation inputs than were needed in the less severe years.

PL_1 is also the most efficient long-run program level if the more severe Year C occurs once every 20, once every 15, or even once every 10 years, representing probabilities of 0.0500, 0.0667, and 0.1000 respectively (table 12).

If Year C occurs once every 5 years or more frequently, then PL_4 is the most efficient long run program. The resource losses averted in the severe years would then be large enough to cover the added program cost in the intervening less severe years.

The impact of varying fire severity years upon the most efficient long-run fire management program in the Willamette highlights the importance of considering the stochastic element in fire management analyses. The stochastic nature of fire occurrences and fire weather

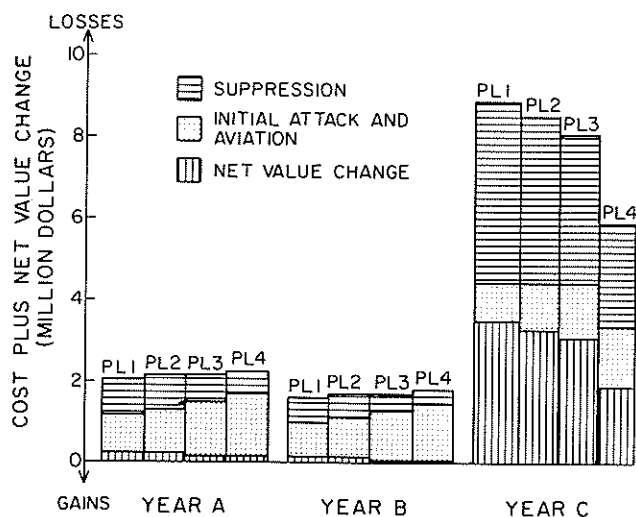


Figure 8—Determinants of minimum cost plus net value change are evident in the chart for the Willamette National Forest.

Table 12—Expected value *C* + *NVC* for the Willamette National Forest case study under varying probabilities of the three fire years by program level

Probability of occurrence			Expected value <i>C</i> + <i>NVC</i>			
Year A	Year B	Year C ¹	PL ₁	PL ₂	PL ₃	PL ₄
Thousand dollars						
0.4875	0.4875	0.0250	² 2020	2117	2104	2176
.4750	.4750	.0500	² 2196	2283	2262	2275
.4667	.4667	.0667	² 2314	2394	2367	2358
.4500	.4500	.1000	² 2549	2615	2576	2473
.4000	.4000	.2000	3255	3280	3205	² 2869

¹Corresponding frequencies, reading down, are 1 in 40 years, 1 in 20, 1 in 15, 1 in 10, and 1 in 5.

²Minimum *C* + *NVC* program level.

Table 13—Net value change on the Willamette National Forest by fire year, resource category, and program level (PL₁ lowest)

Fire year and resource category	Net change ¹			
	PL ₁	PL ₂	PL ₃	PL ₄
Thousand dollars				
A:				
Commercial timber	301	296	253	238
Recreation	-1	-1	-1	-1
Total	300	295	252	237
B:				
Commercial timber	159	155	89	74
Recreation	-1	-1	-1	²
Total	158	154	88	74
C:				
Commercial timber	3,287	3,175	3,005	1,976
Water storage	-2	-2	-2	—
Fish habitat	47	47	47	—
Wildlife habitat	120	113	111	35
Recreation	-41	-40	-36	-30
Structures	90	90	90	—
Total	3,503	3,385	3,217	1,981

¹Columns may not add due to rounding.

²Less than \$0.5 thousand.

must be captured in the data and the analysis model must be capable of displaying the consequences of this inherent variation.

Suppression Costs

The cost of fire suppression activities in Year B at PL₂ was \$529,000 or \$2043 per acre burned. This was almost identical to the per acre suppression cost for the Deschutes Forest.

The use of secondary Forest Service suppression forces was heavier for the Willamette than for the other five Forests. The suppression cost by source at PL₂ was as follows:

	Year A	Year B	Year C
Thousand dollars			
Source:			
Primary Forest Service	\$254	\$176	\$ 410
Secondary Forest Service	522	351	3,726
Cooperator	3	2	6
Total	\$779	\$529	\$4,142

The secondary Forest Service source was greater in all 3 fire years and fully 90 percent of the total suppression cost in Year C. The forces funded under initial attack and aviation appropriations are generally used for initial attack and small fire suppression. Secondary forces are used when the fires escapes initial attack or when multiple fire starts deplete the initial attack and aviation capability. The heavier fuel loadings and occasional incidence of multiple fires are two of the causes for this heavy use of secondary source suppression forces on the Willamette.

The low cooperator cost reflects the role of the Forest Service as the supplier of fire program assistance to other agencies in severe fire years. This helps to explain the heavy aviation component in both the Willamette and Deschutes programs, which may create an imbalance for the Forest alone.

Resource Value Change

The net value change in resource outputs in Year A and Year B was a very small percentage of the total C + NVC. Essentially all of the net value change was a reduction in commercial timber outputs due to fire, just as it was for the Deschutes (*table 13*).

The year C net value change was a higher percentage of the total C + NVC than it was in Years A and B. It was also a higher percentage than that of any Forests previously discussed. The net value change in Year C ranged from a high of \$3,503,000 at PL₁ to \$1,981,000 at PL₄. The PL₄ net value change per acre burned was \$1145.

The Willamette National Forest is very heavily forested, and there is substantial harvesting of high-value, old-growth timber. The greatest loss of merchantable timber due to fire, as estimated by the interdisciplinary team of resource experts, was 4500 board feet per acre, even though timber stand volumes 10 to 15 times as large are not uncommon. This suggests that the resource experts recognized the 80 to 95 percent salvage rate which has historically occurred after fire.

The regional average price for timber which was applied in the Willamette case was \$166 per thousand board feet. The actual sale price for timber on the Willamette National Forest in fiscal year 1978 was 70 percent higher. This price underestimate, along with the conservative assumption that timber salvaged after a burn can command the same price as green timber, means that the net value change in this study was underestimated. This underestimate would not affect the selection of the most efficient program level in any one of the fire severity years.

The impact of this timber price change would influence the results of the expected value analysis, however. An increase in the net value change lowers the probability at which Year C must occur before PL₄ is the most efficient long-run program level. For example, if the per unit value of timber were doubled, the threshold probability for Year C would be less frequent than the 1 in 5 years derived from the values in *table 12*. Data errors do not always have a linear effect on study results, even in a marginal analysis.

Fish and wildlife habitat net value changes were not materially affected in Years A and B, but their effect was larger and detrimental in Year C. This in part reflects the sensitivity of some resource effects to the size and intensity of fires, both of which were greater in Year C.

Air and water quality standards were not violated in Years A and B. Fifty days of water quality standards were violated in Year C at PL₁, PL₂, and PL₃. Twenty days were violated at PL₄. Air quality standards were violated 37 days in Year C at PL₁ but declined only to 32 days at PL₄. No unique resources were affected.

SAN BERNARDINO NATIONAL FOREST

The San Bernardino National Forest covers 633,000 acres in southern California east of the Los Angeles basin. The Forest is bounded on the east by desert. It contains more interspersed ownership than the two case Forests in the Pacific Northwest; 78 percent of the land within the boundary is National Forest.

The principal vegetation is chaparral with smaller areas of hardwoods and conifers at higher elevations. A large number of recreationists visit the Forest because of its close proximity to the large southern California population centers and there are a relatively large number of primary and secondary homes on the interspersed privately-owned land. Watershed management is an important activity. The watershed objective is production of both domestic and irrigation water and the prevention of flood damage. The terrain is quite steep and access is moderate.

Fire Years

The number of fires in Year B was 364 and the fire density in Year B was 0.58 fires per thousand acres, higher by far than in any of the other Forests studied. The most severe fire weather occurs when dry, east, Santa Ana winds reduce fuel moisture and substantially increase the fire's rate of spread.

Program Levels Tested

The initial attack and aviation program on the San Bernardino varied from a low of \$6,266,000 at PL₁ to \$11,300,000 at PL₄, the largest program of any of the six Forests. This was an average initial attack and aviation cost at PL₂ of \$11.77 per acre of National Forest land. This was considerably higher than on any of the other five Forests, where the initial attack and aviation cost ranged from \$0.15 per acre on the Huron-Manistee to \$0.66 per acre on the Deschutes. Ninety percent of the PL₁ and 81 percent of the PL₄ program was initial attack. The aviation component of the program was almost tripled between PL₂ and PL₃ while the initial attack component was only increased 4 percent. This, in part, represents an initial PL₂ imbalance of too few aviation inputs, just the opposite of the PL₂ imbalance on the Deschutes.

There is a great deal of cooperation among the several governmental fire control agencies in southern California. As much as possible, the availability of cooperator assistance was held constant as the Forest's initial attack and aviation level was changed to avoid the assumption

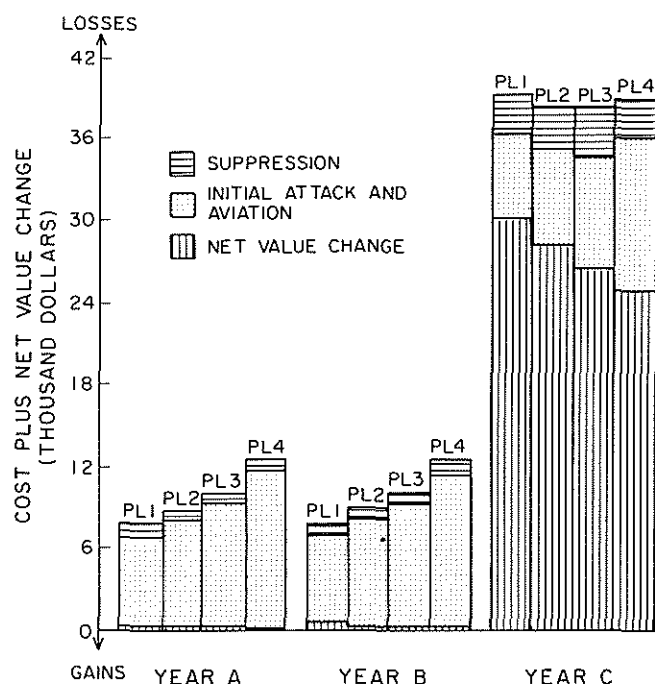


Figure 9—Determinants of minimum cost plus net value change are evident in the chart for the San Bernardino National Forest.

that the cooperators would fill in the slack created by a lower Forest program.

Economic Efficiency Results

The most economically efficient program in Year B was PL₁. Its C + NVC was \$888,000 less than PL₂ (table 14, fig. 9). The total C + NVC at PL₁ in Year B was 77 percent initial attack and aviation cost, 15 percent suppression cost, and 8 percent net value change. Suppression cost and net value change declined as the initial attack and aviation program level increased but not by enough to overcome the increase in the cost of program input. PL₁ was also the most efficient program level in Year A and the C + NVC makeup was similar.

In Year C, PL₃ produced the lowest C + NVC. The suppression costs and net value change decline between PL₁ and PL₃ was greater than the increased cost of the initial attack and aviation program. The composition of the C + NVC was quite different in Year C than in Years A and B: 23 percent initial attack and aviation cost, 7 percent suppression cost, and 70 percent net value change at PL₃. Detrimental effects upon resource outputs were

Table 14—Economic efficiency of fire management program levels as measured by cost plus net value change (C + NVC). San Bernardino National Forest

Fire severity year and initial attack program level	Components of C + NVC			Total C + NVC	Quality standards violations		Simulated area burned
	Initial attack forces budget ¹	Suppression cost	Net value change in resources ²		Air	Water	
	Thousand dollars				Days		Acres
A:							
PL ₁	5,645	1,006	486	⁴ 7,758	46	1,401	4,661
PL ₂	6,895	940	430	8,818	41	1,269	3,702
PL ₃	7,171	852	416	10,011	37	1,354	3,022
PL ₄	9,122	777	226	12,303	37	1,501	2,414
B:							
PL ₁	5,645	1,192	635	⁴ 8,093	21	765	11,860
PL ₂	6,895	1,081	452	8,981	21	730	10,963
PL ₃	7,171	983	372	10,098	14	562	9,897
PL ₄	9,122	907	287	12,494	13	562	9,192
C:							
PL ₁	5,645	2,983	30,037	39,286	29	1,260	57,889
PL ₂	6,895	2,749	28,461	38,658	23	1,434	54,323
PL ₃	7,171	2,572	26,674	⁴ 37,989	23	1,697	51,485
PL ₄	9,122	2,589	25,128	39,017	17	1,186	49,534

¹No aviation operation was included in the program for this Forest.

²Net value change is negative for net beneficial fires (resource outputs greater "with" the fires than "without"), and positive for net detrimental fires. There were no effects on unique resources at any level for any year tested.

³Less than \$0.5 thousand.

⁴Program level with lowest C + NVC; therefore most economically efficient of those tested for that severity year.

higher in total in Year C on the San Bernardino than on any other case study Forest. The C + NVC for PL₁ and PL₂ in Year C was very close to the PL₃ level, only 3 percent and 2 percent higher respectively. This is probably a finer distinction than can be made with the accuracy of this study. In Year C then, where efficiency was almost the same from PL₁ to PL₃, initial attack and aviation program increments were traded almost equally for reductions in net value changes, mostly structural damage in this case.

Since the most efficient program level was sensitive to the severity of the fire year in the San Bernardino, an expected value threshold calculation can be made much as it was for the Willamette Forest. The C + NVC in Year C dropped by \$1,297,000 between PL₁ and PL₃, but it increased in Years A and B by \$2,252,000 and \$2,004,000, respectively. If we assume that the remaining probability is equally split between Years A and B, Year C must occur with a probability of 0.625 or greater before PL₃ gives the lowest expected value C + NVC. At lower probabilities of Year C, PL₁ is the more efficient program. From the historical record of acres burned on the San Bernardino, it appears that a year as severe as Year C is likely to occur far less often than the almost 2 out of 3 years required to make PL₃ the optimum level. As discussed above, these economic efficiency results must be weighted together with social and environmental inputs, which are not included in this study, before a program level decision can be reached.

Suppression Costs

The suppression costs for the San Bernardino Forest were a smaller percentage of the total C + NVC than for any other Forests studied except one. In Year B at PL₂, the suppression costs were \$1,081,000 which was 12 percent of the total C + NVC. The average of \$99 per acre burned was higher than on the two eastern Forests but far less than the per burned acre suppression cost in the two Pacific Northwest Forests.

Suppression costs decreased as the initial attack and aviation program was increased, but they did not drop by much. In Year B, for example, the suppression costs dropped from \$1,192,000 to \$907,000 or 24 percent between PL₁ and PL₄. In Year C, they only declined by 13 percent over the same program level range. In Year C, the suppression costs dropped by \$394,000 in response to a \$5,035,000 increase in initial attack and aviation budget.

This relatively stable suppression cost was paralleled by a similarly stable distribution of fires by fire size class. At PL₁, in Year B, 16 fires exceeded 10 acres and at PL₄, 14 fires exceeded 10 acres, a decline of only two fires and a corresponding drop in total acres burned of only 22 percent. In Year C, the number of fires over 10 acres at PL₁ was 28 and at PL₄ was 25, a decline of only three fires and a corresponding drop in total acres burned of only 14

percent. Burning conditions were so severe in Year C that even the substantial increases in initial attack and aviation program levels between PL₁ and PL₄ were only able to modify the acres burned by a small amount.

The majority of the suppression costs were primary Forest Service firefighting forces. The division by source at PL₂ was as follows:

	Year A	Year B	Year C
	----- Thousand dollars -----		
Source:			
Primary Forest Service	\$617	\$ 583	\$1,865
Secondary Forest Service	166	445	807
Cooperator	157	53	77
Total	\$940	\$1,081	\$2,749

Table 15—Net value change on the San Bernardino National Forest by fire year, resource category, and program level (PL₁ lowest)

Fire year and resource category	Net change ¹			
	PL ₁	PL ₂	PL ₃	PL ₄
	Thousand dollars			
A:				
Commercial timber	134	119	120	138
Commercial forage	-1	-1	-1	-1
Water use	-8	-6	-5	-3
Water storage	1	2	2	2
Fish habitat	5	5	5	4
Wildlife habitat	-1	-9	-13	-14
Recreation	3	2	2	2
Structures	353	320	308	100
Total	486	430	416	226
B:				
Commercial timber	264	127	96	50
Commercial forage	-2	-2	-2	-2
Water use	-18	-16	-15	-13
Fish habitat	2	2	—	—
Wildlife habitat	74	66	59	53
Recreation	4	3	3	3
Structures	311	272	229	194
Total	635	452	372	287
C:				
Commercial timber	2,047	2,042	1,858	1,672
Commercial forage	-4	-4	-3	-3
Water use	-74	-68	-64	-60
Water storage	2	2	2	2
Fish habitat	459	457	457	457
Wildlife habitat	432	406	377	350
Recreation	20	19	18	17
Structures	27,157	25,609	24,031	22,695
Total	30,037	28,461	26,674	25,128

¹Columns may not add due to rounding.

²Less than \$0.5 thousand.

A smaller percentage of the suppression costs was borne by secondary Forest Service sources here than for the Willamette Forest, but they still made a major contribution. Cooperator inputs, which were minimal for the four Forests discussed so far, provided 17 percent of the Year A suppression costs but a small percentage of the Year C costs (3 percent), because in Year C they would be required elsewhere. This reflects the mutual assistance agreements common between fire agencies in California.

Resource Value Change

The net value change on the San Bernardino, 6 and 8 percent, in Years A and B at PL₁, was a small percentage of the total C + NVC. The per acre burned net value change at PL₁ was \$104 and \$54 for those years respectively. The total and per acre net value change declined as the program level increased.

The net value change in Year C was a much higher percentage (70 percent) of C + NVC at the most efficient program level (PL₃) than in Years A or B. The net value change per acre burned was also much higher, \$519 per acre, than in Years A and B. Although this net value change was a higher percentage of the total C + NVC than in any other case study, it was a lower per acre loss than in Year C on the Willamette where high value timber was affected. The net value change per acre burned at the most efficient program level on the Willamette (PL₄) in Year C was \$1145.

There was some loss of commercial timber on the San Bernardino in all 3 fire years (table 15). The timber impact was probably overestimated, however, since the fiscal year 1978 stumpage price on the Forest was only 30 percent as large as the \$166 per thousand board feet regional average price used in this study. The change in the stumpage price data would moderately reduce the estimated net value change but it would not affect selection of the most efficient program level.

In Year B, there was a detrimental effect on wildlife and recreation output and a beneficial effect on forage output. These nontimber effects were greater in Year C but in total were much smaller than the commercial timber or structural effects.

The majority of the net value change in all years was structural loss. The Year C structural loss at PL₃ was \$24,000,000, 90 percent of the net value change and 63 percent of the total C + NVC. On average, the net value change in the structural category, for both structures burned and those affected by increased waterflows after the fires, was distributed in the following manner:

<i>Structural class</i>	<i>Percentage of structural net value change</i>
1. Water-related structures, including "trash racks," designed to stop the downstream flow of large debris, and debris basins, designed to slow water velocity enough that silt and other fine debris can settle out.	45
2. Forest management structures, such as fences and cattle guards.	5
3. Public utilities, such as powerlines and telephone lines.	5
4. Privately owned structures on the Forest under special use permit, primarily second homes.	15
5. Second homes on private in-holdings within the Forest boundary.	15
6. Primary residences on private in-holdings within the Forest boundary.	15

All structures were valued at their replacement cost. That valuation approach which measured the actual benefits derived from the structures was beyond the scope of this study. No fire effects were estimated beyond the Forest boundary in the San Bernardino case. This leads to a net value change underestimate by an unknown amount. The San Bernardino study results must be used with caution unless the assumption is made that the off-Forest fire effects are the same at all four program levels.

The large impact on water-related structures and the detrimental impact on fish habitat is a result of the steep terrain and the highly erodible soils on the Forest. The increased waterflow following the fire's removal of vegetation also leads to stream siltation in excess of the water quality standards to a much greater extent on this Forest than in any other case study. In Year C at PL₃, for example, the 499 fires that burned 51,485 acres would result in an estimated 1697 days of water quality standard violation, partly because several streams were affected. Air quality standards were violated 23 days in the same year at the same program level. Adverse effects on unique resources were listed for archeological sites, one sensitive plant species, and a 200-year loss of habitat for the bald eagle, spotted owl, and rubber boa. Beneficial effects were listed for wildlife habitat diversity, two sensitive plant species, and burro forage.

The high total losses in Year C on the San Bernardino again highlight an important element in the evaluation of fire management program efficiency. The absolute magnitude of the fire loss is not relevant in determining the most efficient program level. What is relevant is how much of the losses can be averted under different program levels. The added cost of a program increment must be offset by equal or greater reductions in the combined suppression cost and fire losses. If they are not, the increment is not an efficient addition no matter how large the absolute loss is.

TONTO NATIONAL FOREST

The Tonto covers 2,875,000 acres in west-central Arizona adjacent to the Phoenix metropolitan area. Almost all of the land within the boundary, 97 percent, is National Forest ownership. The principal vegetation types are desert shrub at the lower elevations, conifer timber at the higher elevations, and chaparral and oak woodlands in the intervening elevations. The wide variation in elevation and associated rainfall within the Forest has resulted in many rare or unique plant and animal communities. Water production and water-oriented recreation are important outputs from the area.

Fire Years

The fire season is normally most severe during May and June. Burning conditions are normally moderated by heavy thunderstorm activity during July and August. There were 251 fires in Year A, 278 fires in Year B, and 262 fires in Year C. The average number of fires in Year B was 0.10 per thousand acres of Forest land, lower than any other Forests studied.

Program Levels Tested

The initial attack and aviation program levels analyzed here varied from \$1,175,000 at PL₁ to \$2,056,000 at PL₄. This was achieved by ± 20 percent increments in both the initial attack and aviation components of the program. The average initial attack and aviation cost at PL₂ was \$0.51 per acre of Forest land. This was higher than for the two eastern Forests, about three-quarters as large as the Pacific Northwest Forests, and considerably lower than the \$11.77 per acre cost for the San Bernardino.

Economic Efficiency Results

PL₃ was the most economically efficient program level in Year B (table 16). PL₃ was also the most efficient in Years A and C, so again the fire season severity did not affect selection of the most efficient program level even though it did influence the total C + NVC.

The net value change contribution to C + NVC in Years B and C was very small, never reaching more than 4 percent. The suppression cost component was larger in Years B and C than on any other Forest studied, reaching 55 percent in Year B and 61 percent in Year C. The suppression cost declines much more in this case in response

Table 16—Economic efficiency of fire management program levels as measured by cost plus net value change (C + NVC), Tonto National Forest

Fire severity year and initial attack program level	Components of C + NVC			Total C + NVC	Quality standards violations		Simulated area burned
	Initial attack forces budget ¹	Suppression cost	Net value change in resources ²		Air	Water	
	Thousand dollars				Days		Acres
A:							
PL ₁	981	3,536	1,596	6,307	7	9	22,306
PL ₂	1,226	1,463	1,229	4,160	7	0	6,114
PL ₃	1,471	907	625	²³ 3,295	2	0	1,519
PL ₄	1,716	865	625	3,546	2	0	1,738
B:							
PL ₁	981	5,705	185	7,065	22	19	39,204
PL ₂	1,226	3,849	203	5,521	14	0	23,206
PL ₃	1,471	2,188	6	²³ 3,957	13	0	8,644
PL ₄	1,716	2,039	2	4,097	21	0	7,658
C:							
PL ₁	981	8,595	215	9,985	10	21	54,260
PL ₂	1,226	4,357	52	5,878	10	0	27,869
PL ₃	1,471	2,788	52	²⁴ 4,603	9	0	13,838
PL ₄	1,716	2,833	53	4,942	9	0	13,769

¹No aviation operation was included in the program for this Forest.

²Net value change is negative for net beneficial fires (resource outputs greater "with" the fires than "without"), and positive for net detrimental fires. There were no effects on unique resources at any level for any year tested.

³Less than \$0.5 thousand.

⁴Program level with lowest C + NVC; therefore most economically efficient of those tested for that severity year.

to initial attack and aviation increments than in any other Forest studied. In these 2 years, the suppression cost changes are solely responsible for the location of the most efficient program level (*fig. 10*).

The fire start locations in Year A happen to be near structures, so in that year the net value change contributed as much as 30 percent of the total C + NVC. Remember that the 3 fire years simulated are separate historical years with unique fire start locations and fire weather conditions. In Year A, the program cost increase between PL₁ and PL₃ was less than the reduction in net value change. Suppression costs contributed a larger share of the C + NVC than the net value change at all program levels, however, and suppression costs declined even more than net value change with increase in the program level.

One question prompted by the comparison of suppression costs and net value changes in Years B and C is why so much was spent on fire suppression when the net value change was so small. Alternative program levels and strategies for suppression of escaped fires were not evaluated in this study, however, so there is no way of determining from these results alone whether the suppression cost was an efficient or inefficient expenditure. The ratio of suppression cost to net value change indicates, however, that alternative suppression strategies should be studied.

Suppression Costs

The PL₂ suppression cost on the Tonto in Year B was \$166 per acre burned, higher than the San Bernardino but still far less than the \$3655 on the Deschutes and \$2043 on the Willamette.

The total suppression costs are high on the Tonto because lightning storms often produce multiple fire starts which, if left unattended in the "flashy" grass and brush fuels and steep terrain, spread to a large size quickly. Restricted access on much of the Forest has led to a program heavily weighted toward aircraft retardant drops and helicopter transport of fire crews. Aircraft costs accounted for about half of the total suppression cost, well above the national average.

The increased initial attack and aviation programs, coupled with aggressive fire suppression activities, led to a significant decline in simulated acres burned, in Year B, for example, from 39,204 acres at PL₁ to 7658 acres at PL₄. The average fire size declined over the same program range from 142 acres to 28 acres per fire. The simulated suppression strategy was effective at keeping fires smaller, but it was expensive relative to the amount that net value change declined.

The majority of the suppression cost was borne by primary Forest Service sources. Cooperator sources were a higher percentage of the total than for any other Forest, 19 percent in Year B at PL₂. The relative suppression costs by source at PL₂ were as follows:

	Year A	Year B	Year C
Source:	----- Thousand dollars -----		
Primary Forest Service	\$ 948	\$2,683	\$2,943
Secondary Forest Service	113	433	494
Cooperator	402	733	920
Total	\$1,463	\$3,849	\$4,357

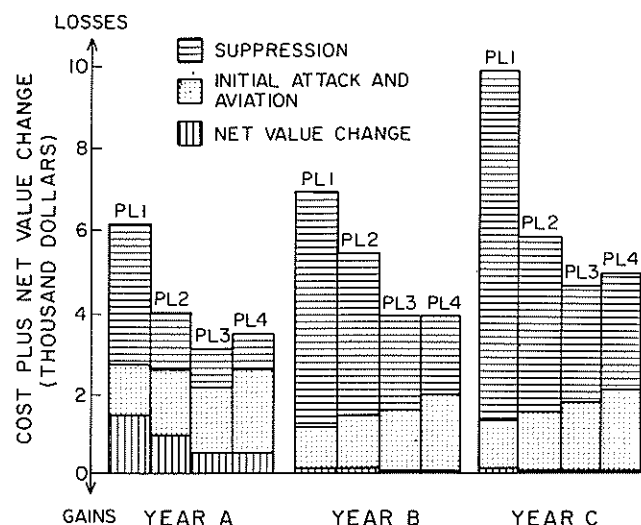


Figure 10—Determinants of minimum cost plus net value change are evident in the chart for the Tonto National Forest.

Resource Value Change

The greatest net value change in Years A and B comes from structures, primarily fences, bridges, and other administrative structures (*table 17*). The wildlife habitat output, as measured in user days by recreationists for consumptive and nonconsumptive uses, is increased in Years B and C by fire. The recreation resource output is reduced, particularly in Year C. Recreational use is concentrated along the scarce water courses and the camping facilities are usually filled to capacity. The effect of a single fire on recreational usage therefore will probably lead to an equal amount of change in net recreational usage. There is no unused capacity for the displaced recreationist to move to. Commercial timber impacts are a smaller percentage of the total net value change. Water quality standards are violated in all years only at PL₁, and air quality standards are violated from 2 to 22 days, depending upon year and program level.

Table 17—Net value change on the Tonto National Forest by fire year, resource category, and program level (PL₁ lowest)

Fire year and resource category	Net change ¹			
	PL ₁	PL ₂	PL ₃	PL ₄
<i>Thousand dollars</i>				
A:				
Commercial timber	5	1	2	2
Commercial forage	2	2	2	2
Water use	-3	-1	-2	-2
Water storage	2	2	2	2
Wildlife habitat	-5	-3	-2	-2
Recreation	6	2	2	2
Structures	1,593	1,232	627	627
Total	1,596	1,229	625	625
B:				
Commercial timber	1	1	2	2
Commercial forage	-1	-2	-2	-2
Water use	-2	-1	1	-1
Water storage	2	2	2	2
Wildlife habitat	-22	-9	-5	-5
Recreation	7	2	1	1
Structures	202	210	11	7
Total	185	203	6	2
C:				
Commercial timber	92	10	2	1
Commercial forage	-1	-1	-1	-1
Water use	-2	-2	-1	-1
Water storage	2	2	2	2
Fish habitat	1	2	—	—
Wildlife habitat	-50	-32	-15	-14
Recreation	114	59	55	54
Structures	61	18	14	14
Total	215	52	52	53

¹Columns may not add due to rounding.

²Less than \$0.5 thousand.

CONCLUSIONS

The results of this study should be interpreted only within the context of several important limitations of the study method. First, this was a marginal analysis of the fire management program. The C + NVC efficiency criterion by its nature is a measure of marginal efficiency. It measures the economic efficiency of the added program increment but it does not give a measure of the efficiency of the total program to which the increment is being added.

Second, this was a partial, as opposed to a total analysis. The cost of most, but not all, of the program inputs were measured and the net value change of most, but not all, of the resource and structural impacts of fires was measured. Some fire effects, such as violations of air and

water quality standards, were measured only in physical terms. The only major direct fire effects excluded were human life and soil productivity. Secondary impacts were excluded. These added impacts must somehow be added to the C + NVC estimate before a final decision on the best fire management program can be reached.

Third, the analysis covered only a sample of the possible conditions that fire management programs face nationwide. The six Forests encompassed a wide range of fuel, weather, resource, and fire occurrence conditions, but other combinations exist. The selection of 3 historical years of varying fire severity is also a small sampling of the full range of fire severity conditions which can exist.

Last, the analysis included variations in only the initial attack and aviation components of the fire management program on the Forest. Changes in these program components have impact on the efficiency of the other components of the fire management program and on the efficiency of resource programs on the Forest. They also affect the use of fire management inputs shared among several Forests, such as smokejumpers. To the extent that the cost of inputs used beyond the Forest's fire management program were not included in this analysis, this study method will lead to a suboptimum solution that is biased toward a smaller Forest-level fire management program.

Some limitations encountered in this study must eventually be overcome before a more complete economic analysis of alternative fire management programs can be constructed. First, estimates of effectiveness of program alternatives for all five major components of the fire management program (prevention, detection, initial attack, escaped fire suppression, and fuel treatments) must be incorporated within a single model construct. Only then can trade-offs between the components be measured effectively. The high suppression cost and low net value change in the Tonto case study, for example, indicates that a joint analysis of alternative initial attack programs and suppression strategy is needed. This analysis of initial attack and aviation alone has the potential of leading to severe suboptimization even within the fire management program.

Second, the analysis should be expanded to include the fire management program inputs which are shared among individual forests. Smokejumpers, air tankers, and some helicopters fall into this class. The size and composition of the pool of shared inputs was held constant in this study at all Forest program levels.

Third, the range of the program levels tested should be wider than the program range in this study to ensure that the minimum C + NVC is located. The most efficient program level in this study was one of the two end points (PL₁ or PL₄) in 13 of the 17 years studied. Under these conditions, there is no assurance that the overall program level which minimizes the C + NVC was found.

Fourth, alternative fire management program compositions or program mixes should be evaluated separately at each program level. The results for the Deschutes and San Bernardino Forests demonstrate that the program mix or

balance influences economic efficiency much as the program level does. It is unlikely that judgment and intuition alone can lead directly to the most efficient program mix any more than judgment alone can lead directly to the most efficient program level. Both level and mix must be varied in a structured and systematic way to locate the jointly optimum combination.

Fifth, the stochastic element must be more completely incorporated throughout the entire analysis. The random variations in fire occurrence and fire weather variations must be translated into a probability distribution of resource effects and $C + NVC$ itself. The most efficient long-run program can then be identified. The expected value $C + NVC$ and the risk associated with an expected value decision could also be more clearly calculated from a full $C + NVC$ probability distribution than from the three points represented in this study by the varying fire severity years.

Last, even though the preliminary sensitivity analysis in this study demonstrated that errors in the fire effects and resource value estimates would not materially affect the economic efficiency answers in most instances, the accuracy of much of the fire effects data and some of the resource value data is still suspect. More thorough sensitivity analyses should be completed with a prototype analysis model which contains the additional attributes described here. The results of that sensitivity analysis will help establish priorities for future data acquisition.

The fire management analysis and planning model being used on individual National Forests (U.S. Dep. Agric., Forest Serv. 1980c) contains some of these model improvements, such as incrementing the program level until the minimum $C + NVC$ is located, and calculating the expected value fire weather and fire occurrence input rather than evaluating the fire program options against the fire conditions of selected historical years. Similarly, Mills and Bratten (1981) describe the conceptual design of a probabilistic fire economic evaluation system (FEES) which addresses most of these suggested analysis improvements. In particular, FEES evaluates fire program mixes, which include fuel treatments, initial attack and aviation, and large fire suppression components. It also produces the $C + NVC$ probability distribution as well as its expected value. The full probability distribution permits a much more complete analysis of risk.

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APPENDIX

Following are examples of the presuppression fire program activities charged to each major Forest Service budget line item.

111 Forest Fire Prevention

Includes the expenditures primarily incurred for fire prevention activities which are intended to help prevent the occurrence of fires. Examples would be installation and maintenance of effective prevention display facilities; publicity, exhibits, lectures, and other educational activities; issuance of camping and campfire permits; spark arrestor inspections of chain saws, and registration of visitors; enforcement of closed area restrictions; patrols; caution of visitors and users, fire law enforcement including fire origin investigation and preparation and distribution of circular letters on fire and other fire prevention material.

112 Forest Fire Detection

Includes the expenditures primarily incurred for the detection of forest fires. This includes fixed and mobile detection, infrared detection, electronic detection, and both ground and aerial observers whose primary job is to look for and report the occurrence of forest fires. Includes aircraft costs involved in the use of aerial detection.

113 Forest Fire Attack Forces

Includes the expenditures primarily incurred to maintain manpower, equipment (other than aircraft) and supplies in a state of readiness for the immediate suppression of forest fires. It also includes those additional preplanned forces held in reserve to be activated when initial attack fails to control a fire—such as interregional crews, hot-shot crews, and specialized equipment which are available for use on a region or nationwide basis. Travel and transportation costs to move attack forces in behind other attack forces that were dispatched on initial attack will be charged here. Includes payments to State agencies and private associations under fire protection agreements. Mobilization of initial attack forces to a staging area in anticipation of fire will be charged here.

114 Forest Fire Aviation Operations

Includes the expenditures primarily incurred to provide the aviation portion of initial attack and the support items for aviation operations which will be used in fighting forest fires except aerial detection (function 112) and retardant plants (function 116). Includes items such as non-WCF pilots, aircraft specialists, airbase fees, airbase operations, aircraft availability, WCF-fixed ownership rate, safety equipment and aircraft inspection, contract payments, and other related costs.

115 Forest Fuels Management

Includes the expenditures primarily incurred to dispose of, reduce, manipulate, and/or modify forest fuels to meet fire management objectives.



The Forest Service of the U.S. Department of Agriculture

- ... Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.
- ... Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.
- ... Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

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

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

Two components of fire management programs were analyzed at these Forests: Francis Marion (South Carolina), Huron-Manistee (Michigan), San Bernardino (California), Tonto (Arizona), and Deschutes and Willamette (Oregon). Initial attack and aviation operations were evaluated by the criterion of minimizing the program cost plus the net value change of resource outputs and structures resulting from fire ($C + NVC$). Four alternative program or budget levels were investigated at each Forest for each of 3 years of varying fire severity. The program levels ranged from 20 percent below the 1979 funding level to 40 percent above that level. The most economically efficient levels were -20 percent at four Forests, +20 percent at one Forest, and +40 percent at another Forest. Results suggested that increased fire year severity may not mean that a higher program level is more efficient. Commercial timber and structural losses contributed most to net value change, which was a small percent of the $C + NVC$ in most of the years evaluated.

Retrieval Terms: fire economics, initial attack, aviation operations, fire suppression, marginal analysis, economic efficiency, risk