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Estimating Cost of Large-Fire Suppression for Three Forest Service Regions

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Although forest fires in the United States exceeding 100 acres (40 ha) occur only rarely, they account for about 90 percent of the total acreage burned. They also account for about 75 percent of costs of suppressing fires on National Forest lands.[1] Because of the rarity of such fires at most locations, managers find it difficult to estimate a representative cost accurately for the "average" large fire expected at a given location. Only a few studies have been published in which the costs of large-fire suppression have been examined. Consequently, studies of fire management efficiency commonly use simple estimates of large fire costs, such as a fixed cost per acre. Such estimates may be inaccurate due to inadequate accounting information. Cost estimates for fires on Forest Service-administered lands are based on the Individual Fire Reports (Form 5100-29), but only a few broad cost categories are used.

To fund and manage fire suppression programs more efficiently, the National Forests and most States now use the National Fire Management Analysis System (NFMAS).[2] Another system—USDA Forest Service's Fire Economics Evaluation System (FEES)[3] —differs from NFMAS in that it uses a more probabilistic approach. Both systems share similar goals: to estimate total fire suppression costs and losses expected at different levels of program funding.

Estimating large-fire costs entails a number of difficulties. The costs attributed to individual fires may not include significant expenses borne by other administrative units or incurred as overhead. No procedure has been established for considering these indirect costs. If previous fires of a similar size are used to estimate costs of future fires, the question arises: How representative are these costs? Budget allocations may be affected by fire-cost estimates—and this relationship can serve as an unconscious motivation to overestimate representative costs. Few areas have enough large fires to allow the costs of all pertinent factors to be determined. Furthermore, fire management practices and policies have changed over the years. Some of the older fires may not reflect the new fire suppression strategies and, therefore, the cost of similar fires today.

This note describes a statistical technique that can be used to estimate future annual large-fire suppression costs, given the information on fire size distribution developed in fire planning models. The technique, based on total costs of fire suppression, is used to develop regression equations for three Forest Service Regions. The best overall fits use an estimate of the fire line perimeter, proportional to the square root of fire size, and divide the data into two 6-year periods. The predictions using this approach have a low error for the Pacific Northwest Region, and a

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The annual costs attributable to large fire suppression in three Forest Service Regions (1970-1981) were estimated as a function of fire perimeters using linear regression. Costs calculated on a per chain of perimeter basis were highest for the Pacific Northwest Region, next highest for the Northern Region, and lowest for the Intermountain Region. Recent costs in real terms for the Intermountain and Pacific Northwest Regions are lower when adjusted for fire sizes, indicating that cost calculations based on pre-1976 data may overestimate current costs.

Retrieval Terms: forest fires, economics, fire planning, fire suppression costs

higher error for the other two Regions: Intermountain and Rocky Mountain. The approach appears to be well suited for the Pacific Northwest Region, but the larger error for the other two Regions makes it less useful there.

LARGE-FIRE COSTS IN MODELING

The current NFMAS Users Guide[4] directs users to estimate large fire costs from previous fires. If the cost information used in planning models is based on a few atypical fires, misallocations of resources could result. A wide range of fire cost estimates were used by National Forests in the Intermountain Region (R-4), based on the Individual Fire Reports and Large Fire Reports *(table 1)*.[5] Most of the cost variations reflect differences in the types of fuels and fire conditions on the forests and suppression distance from fire bases. The four National Forests with the highest costs—Boise, Challis, Salmon, and Payette—are all located in central Idaho, while the other National Forests in the Region are in Nevada and Utah. Considerable cost disparities exist between National Forests within the same general areas or having the same general fire conditions. The differences in estimated costs between large and small fires also show considerable variation between Forests. When planning on a Regional basis, managers need to know the relative cost differences between Forests. If estimates are made by different people on each Forest, differences in actual conditions and differences in opinions and judgment cannot be separated. The Intermountain Region report stated fire managers felt that standards should be established for suppression costs, in order to overcome these problems.[5]

In the FEES model, the large fire size distributions are based on historic data fitted to Weibull distributions. Fire size classes are established, and costs are assigned to weighted size class means. Because the FEES results were designed to be applicable across similar areas, cost estimates were needed which reflected costs on a range of sites. To obtain large fire cost estimates to test the FEES model, we found that past studies had usually used a single cost per acre value, which was often more of an assumption than an estimate. Because we could find no published estimates for the geographical area of the study, it was necessary to devise an approach that could use existing information to estimate this critical factor of large-costs in fire management efficiency. In an earlier study, similar to the one described here, we estimated large fire costs that were used in a test of FEES, in the Northern Rocky Mountains.[6,7] The present study uses a larger data base and corrects for errors in our previous analysis.

Table 1—*Fire suppression costs estimates for nine National Forests, USDA Forest Service Intermountain Region, by fire size, 1982*

National Forest, State Zone[1]	Fire size (acres)		
	10-99	100-299	300 +
	1982 dollars/acre		
Boise, Idaho			
Zone 3	4,000	2,000	1,000
Zone 1,2	3,500	1,000	500
Challis, Idaho			
Zone W	1,600	1,300	500
Zone O	1,200	9,00	600
Salmon, Idaho			
Zone R	1,200	500	300
Zone M	500	500	300
Payette, Idaho			
Non-Wilderness	900	600	450
Wilderness	900	600	350
Toiyabe, Nevada and Calif.	[2]300	184	184
Fishlake, Utah	115	229	94
Manti-LaSal, Utah	99	99	99
Dixie, Utah	80	50	50
Humboldt, Nevada	76	96	96

Source: See end note 5.

[1]Zone designations identify Forest Service planning areas.

[2]Cost for Toiyabe 10-99 acre fires reported in dollars/fire.

METHODS

On average, the per acre cost of fire suppression can be expected to fall as fire size increases *(table 1)*. While per acre cost estimates based on Individual Fire and Large Fire Reports are constant above 300 acres, the actual costs can probably be expected to continue to decline as fire size increases. For larger fires, most activities, including mop-up efforts, are primarily adjacent to the fire perimeter. Since the ratio of the perimeter to area decreases as the area increases, the costs measured on a per area basis are also likely to fall.

Many factors influence the cost of suppressing wildfires besides fire size. Factors such as fire intensity, weather conditions, values at risk, fuel type, difficulty in line construction and types of equipment used will influence costs. Suppression efforts will likely be more intense if valuable resources or structures are at risk. In some cases fire will be allowed to burn additional area to save suppression expenses. This condition could produce the anomalous result of small fires having high total costs, while larger fires burning under similar conditions have lower total costs. While these different strategies may exist, they cannot be considered easily in fire planning models, so that we have used the simplifying assumption of average costs being proportional to size.

Another factor that contributes to the cost of large fires is the additional overhead personnel assigned as the fire reaches "project" status, when specialized personnel are brought in to manage the fire. However, since there is no fixed size at which a fire reaches project status, it is not a critical factor in our approach.

Our approach starts with the total Regional expenditures and allocates them to the actual fires of that year, on the basis of fire size. If costs are assumed to be proportional to fire line length, it would be preferable to have data on the perimeter length of the fires, rather than total acres burned. Fire perimeter information is not, however, generally available. For this study, we used the estimate that the fire perimeter length was 1.5 times the circumference of a circle enclosing the same area.[8] In this relationship, the length of a fire perimeter is proportional to the square root of the area, namely:

$$\text{length in chains} = 16.82 * (\text{area in acres})^{0.5}$$

The relationship is derived in the following way:

$$\text{area of a circle} = \text{Pi} * r^2;$$

$$\text{perimeter of a circle} = 2 * \text{Pi} * r;$$

$$\text{perimeter} = 2 * \text{Pi} (\text{area} / \text{Pi})^{0.5};$$

$$10 \text{ chains}^2 = 1 \text{ acre};$$

$$\text{perimeter of a fire in chains} = 1.5 * \text{perimeter of a circle with same area};$$

$$\text{perimeter of a fire in chain} = 3 * \text{Pi} (\text{area in acres} * 10 / \text{Pi})^{0.5};$$

$$\text{perimeter of a fire in chains} = 16.82 (\text{area in acres})^{0.5}.$$

The relationship of perimeter to area can vary with each fire, because of natural conditions and suppression efforts. Consequently, some error will be associated with costs estimated on the basis of fire perimeter. But the advantage of this approach is that these cost estimates, will, on average, be the same costs as actually spent.

Suppression cost data for the fiscal years 1970-1981[9] were obtained for three Forest Service Regions: the Pacific Northwest Region (R-6), the Intermountain Region (R-1), and the Rocky Mountain Region (R-4). These costs represented Regional fire program suppression expenditures for those fiscal years, including both National Forest and Regional level resources. Costs were adjusted for inflation by using the Federal Government's Purchases of Goods and Services Price Index,[10] so that all costs were in 1982 constant dollars. To adjust for the small fires (less than 100 acres) costs, an average cost per small fire was calculated, based on the total cost in years where there were no or few large fires. This value ($2,000 in 1982 dollars), was multiplied by the number of small fires for each year, and subtracted from the total cost for that year.

The list of fires, by fire size, was obtained from the National Forest Fire Reports[11] and from a search of the Forest Service computer files of the Individual Fire Reports (Forest Service Form 5100-29). Inconsistencies and omissions of large fire occurrences were found in the listing when it was checked against the more general information found in the National Forest Fire Report. Inconsistencies about fire occurrences which could not be resolved comparing these two sources were resolved through discussion with Forest personnel.

Because the fire costs were listed by fiscal year and the fires were listed by calendar year, a classification of fires, by fiscal year, was necessary. Before 1976, the Federal fiscal year began on July 1 of the preceding calendar year; in 1976, the fiscal year was changed to begin on October 1. Fires occurring after July 1 for calendar years 1970-1975 and after September 30 for calendar years 1976-1981 were recorded as occurring in the following year.

A weighted regression analysis was used to fit the annual large fire cost of each Regional fire program to the total estimated perimeters of the fires for each year, the total acres burned, and the number of large fire occurrences. Separate regression equations were used for each Region because of the suppression costs differences expected between Regions[12] and because of the different types of fire conditions faced by these Regions.

RESULTS AND DISCUSSION

In the regression fits that used only perimeter, estimates were better (i.e., had a lower standard error) than those using other or additional variables like number of fires and fire areas. The model used was:

$$\text{Annual cost}_i = B * \text{Sum of est. perimeter}_i + \text{error}_i/\text{no. of fires}_i \qquad (1)$$

in which $_i$ represents the year, and B is a coefficient representing cost per perimeter length.

The models for the Intermountain and Pacific Northwest Regions tended to produce estimates that underestimated the annual costs in the first 6 years and overestimated them for the last 6 years. To adjust for this change over time, we used the model:

$$\text{Annual cost}_i = B_1 * (\text{Sum of est. perimeter}_i * D_1) + B_2 * (\text{Sum of est. perimeter}_i * D_2) + \text{error}_i/\text{no. of fires}_i \qquad (2)$$

in which i represents the year;

B_1 and B_2 are coefficients representing cost/perimeter length;

D_1 and D_2 are dummy variables:

D_1 = 0 for years 1976-81, 1 for years 1970-75

D_2 = 1 for years 1976-81, 0 for years 1970-75

Table 2—*Estimated fire suppression costs by regression analyses for three USDA Forest Service Regions, by time periods*

Item	Region		
	Northern Costs (s.d.)	Intermountain Costs (s.d.)	Pacific Northwest Costs (s.d.)
Time period:		*1982 dollars/chain*	
1970-81[1]	1,594 (166)	474 (74)	3,359 (1,177)
1970-75[2]	1,568 (227)	826 (104)	4,499 (1,634)
1976-81[2]	1,632 (272)	370 (56)	2,129 (1,692)
		1982 dollars	
Average cost/yr	4,234,779	7,099,326	16,455,370
Est. s.e. for average year	2,760,692	2,044,003	2,232,840

[1]Estimates developed using equation 1.
[2]Estimates developed using equation 2.

The inclusion of the two time periods serving as dummy variables improved the regression fits for the Intermountain and Pacific Northwest Regions, as measured by the standard error *(table 2)*. Estimated costs were computed for fires of some particular sizes, in acres, based on the perimeter-to-area relationship and the 1976-1981 cost coefficients for the two-period model *(table 3)*.

The standard errors for Regional average annual costs were relatively high in the case of the Northern and Intermountain Regions (65 pct and 29 pct of the means, respectively) *(table 2)*. For an analysis of 10 fire seasons, these errors as a percentage of the means would be about 20 percent for the Northern Region and 9 percent for the Intermountain Region. The standard error for the Pacific Northwest Region was 13 percent of the mean for an individual year (using the average number of fires) which would be less than 2 percent of a 10-year average. We presume that the factors involved in determining costs in the near future will be more similar to those in the near past (1976-1981) than those earlier.

Whether these levels of precision are sufficient to discriminate between management alternatives used in planning models depends on the precision of the rest of the planning model and the degree of difference of the alternatives being considered. Since planning models have a large number of subjective elements, their overall precision can not be determined in a quantitative way. Lack of availability of documented, verifiable estimates led us to develop the approach proposed here.

The ranking of costs for the Northern Region and the Pacific Northwest Region *(table 2)* agree with that of McKetta and Gonzalez-Caban[12] that per hour costs of fire suppression resources were higher in the Pacific Northwest Region than in the Northern Region. The relative rankings of all three Regions also are consistent with the fire conditions of the Regions, with the highest costs in the Pacific Northwest and the lowest in the Intermountain Region. The Pacific Northwest Region's fires include more fires in stands of large, valuable timber, while the other Regions have a higher proportion of fires in scrub and brush types, where fires expand rapidly but often have little economic effect.

The equations developed here represent a high level of data aggregation as compared to cost estimates developed for individual Forests, such as shown in *table 1*. They increase the number of large fire experiences and provide more current information, but include fires which may not be representative of some parts of the Regions. The additional accuracy provided by considering total costs of all suppression expenditures has to also be weighed against the possible misallocation of costs within the Regions due to varied conditions between Forests. Some Forests may have conditions which will result in costs much different than the average Forest in the Region, but on the other hand, some Forests may not have had enough recent large fires to make independent estimates of costs.

The apparently lower costs in the more recent fires *(table 2)* suggests that the costs of fires experienced several years ago may not accurately reflect current costs when adjusted for inflation. Although we can not identify the cause of these changing costs, factors contributing to this may be: (1) price rises of fire suppression resources which were less than the inflation index, (2) changes in the mix of equipment used to fight fires, (3) changes in accounting procedures, and (4) changes in firefighting policies and strategies. As these factors continue to change, past cost experiences can be expected to become out of date.

Current procedures do not aggregate costs so that estimates can be validated against actual expenditures, including all

Table 3—*Examples of suppression costs, 1976-1981, by fire size*[1]

USDA Forest Service Region, and estimated cost	100 acres (168 ch)	500 acres (375 ch)	1000 acres (532 ch)
		1982 dollars	
Northern			
Cost per fire	274,008	611,625	867,692
Cost per acre	2,740	1,222	868
Intermountain			
Cost per fire	62,160	138,750	196,840
Cost per acre	622	278	197
Pacific NW			
Cost per fire	357,672	798,375	1,132,628
Cost per acre	3,577	1,597	1,133

[1]Estimates developed using equation 2.

program costs. The results of this study could be useful in determining a baseline for establishing more localized costs. Local managers may know where the high and low cost areas are within the Regions, but may not be confident when estimating costs.[5] The judgment of managers now being used to estimate representative local costs directly could be refocused on making adjustments to the Regional averages.

CONCLUSIONS

This study used total costs of fire suppression from three Forest Service Regions as a basis for deriving regression equations. The best overall fits used an estimate of fire line perimeter, proportional to the square root of fire size, and divided the data into two 6-year time periods. The predictions have a low error for the Pacific Northwest Region. This approach is well suited for the Pacific Northwest Region, but the larger error for the other two Regions makes it less useful there. For non-site specific planning models such as FEES, this approach provides empirically based cost estimates consistent with modeling requirements. The results may also be applied to operational studies such as suppression force basing studies.

END NOTES AND REFERENCES

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