EFFICIENCY IN SUPPRESSING FOREST FIRES: A STUDY OF THE SOUTH EAST AREA OF MANITOBA

by

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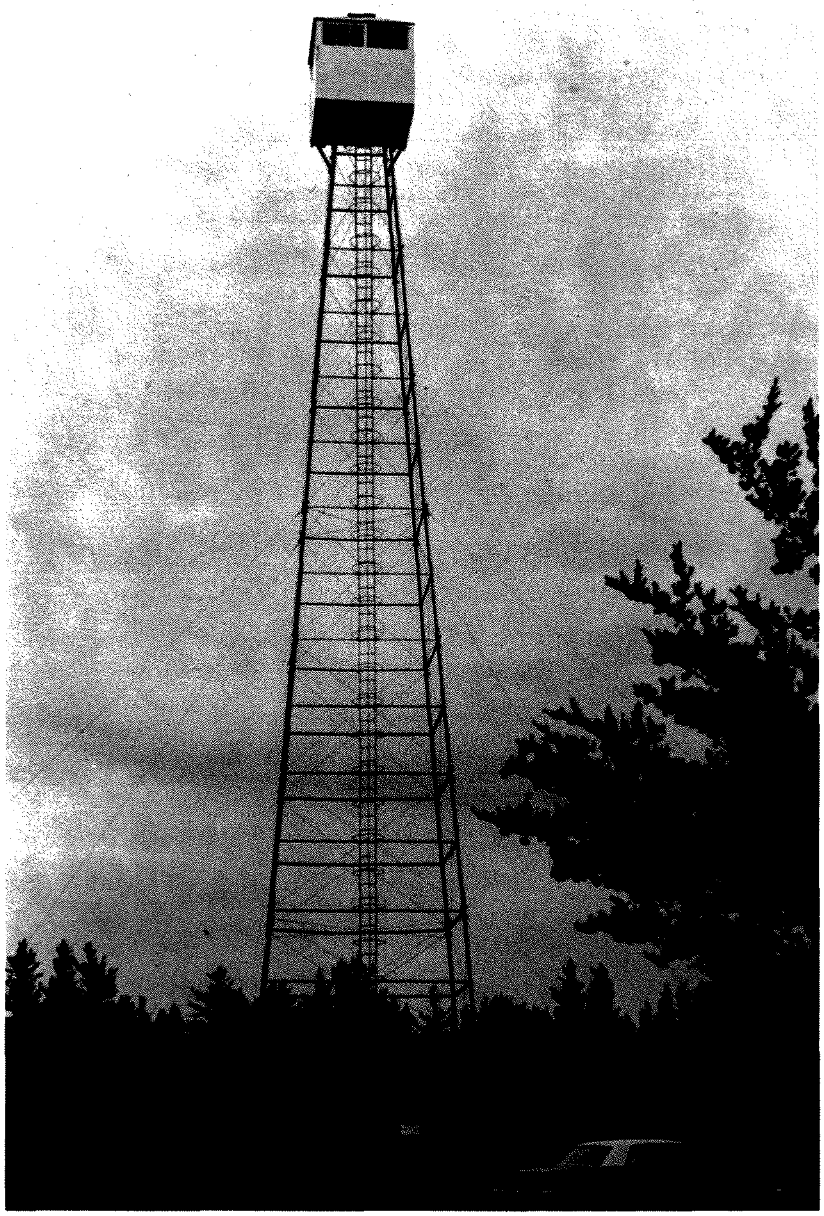

Efficiency in Suppressing Forest Fires: A Study of the South East Area of Manitoba.

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INTRODUCTION

During 1968-1969 a study was undertaken by the Forestry Branch, Department of Fisheries and Forestry, in co-operation with the Department of Agricultural Economics, University of Manitoba, to evaluate criteria for expenditures on forest fire control, with special application to the South East Forest Area of Manitoba.

The results of part of this study are described in this Information Report, which deals with some problems of suppressing fires. The total problem of providing optimum forest protection is, of course, a topic of much wider scope. Protection is a larger or smaller part--depending on one's views--of the total institutional, biological and technical planning and management required for socially good multiple use of forests.

The South East Forest Area is illustrated by Map 1. It is an almost level area of approximately 2,600 square miles containing a wide diversity of soils and forest types. It includes some villages and agricultural areas as well as expanses of woodland used in part for timber production, outdoor recreation, and as habitat for wildlife.

METHODS

Information on the occurrence of fires, areas burned, rates of spread, and men and equipment employed in detection and suppression was obtained from Fire Reports and from discussions with forest protection officers in Winnipeg and in the South East Area. Meteorological data were obtained from reports of local weather stations.

Ideas for the study, opinions about the quality of recorded data, and unrecorded information were gathered in discussions with forest protection officers, commercial wood users, and the public.

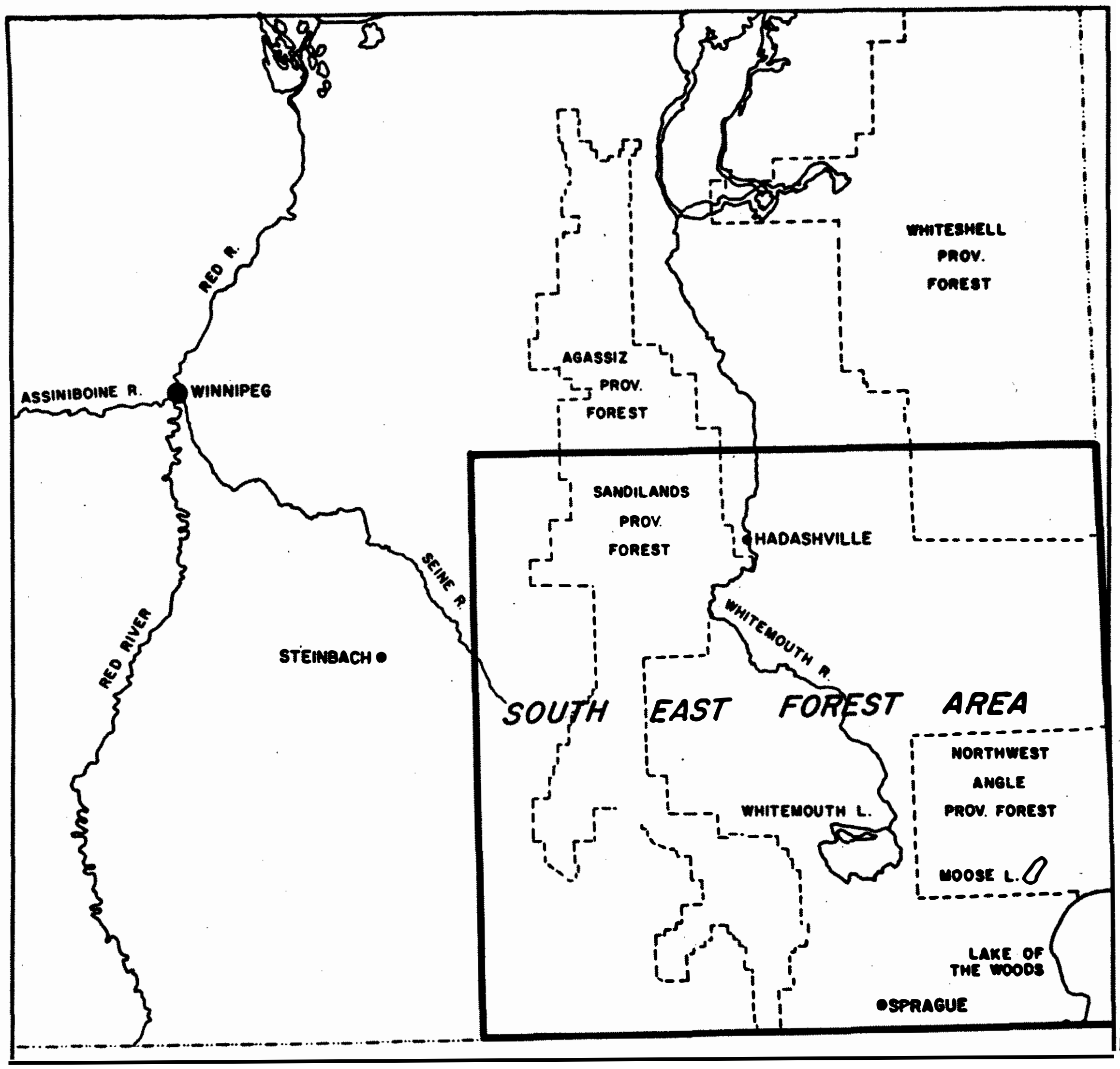
Multiple regression and analysis of variance have been used to assist in interpreting the data on fire behavior and the success of alternative suppression inputs, and inferences have been drawn about cause-and-effect relations.

RESULTS AND DISCUSSION

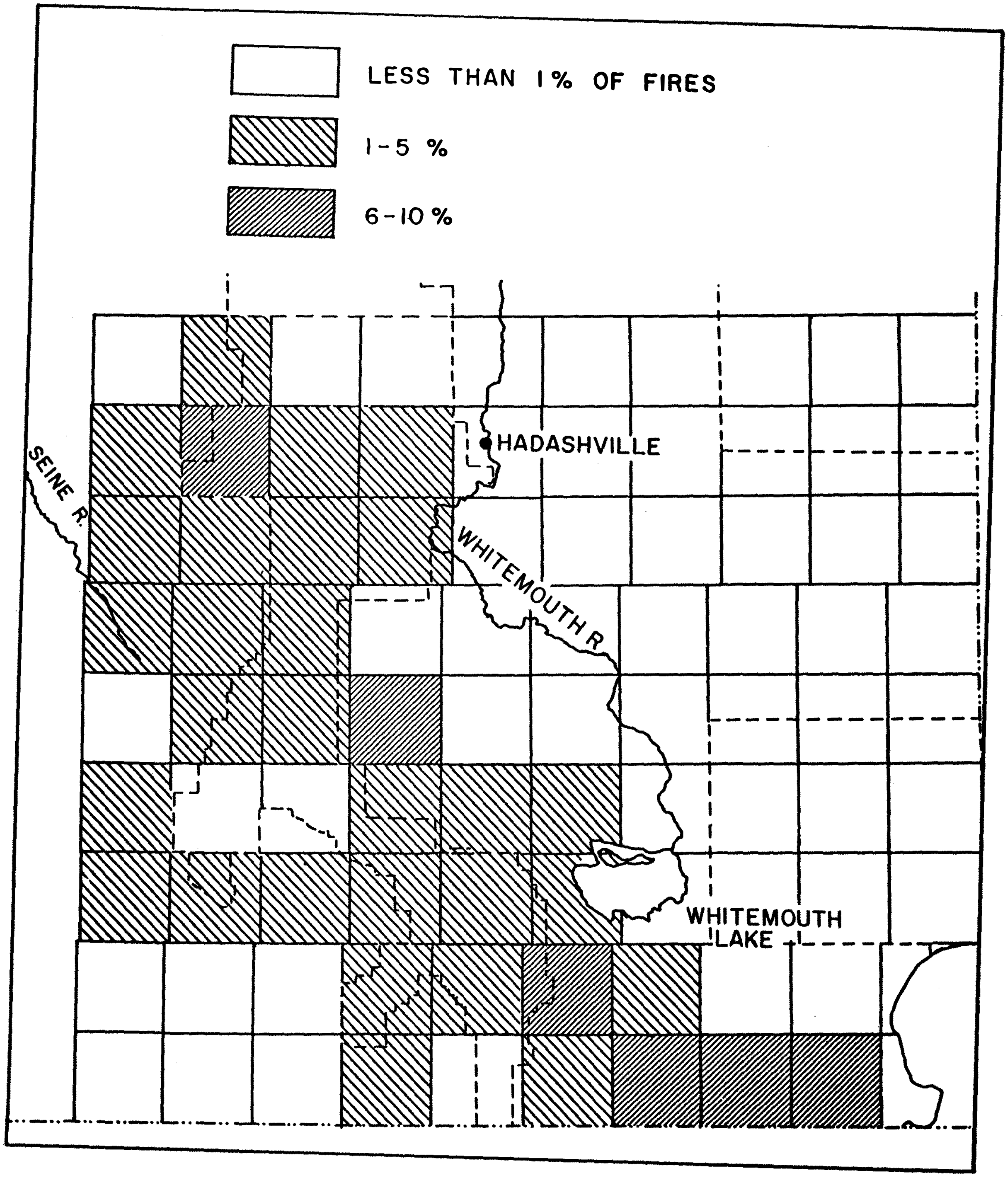
Location of Fires and Protection Forces

Map 2 shows, in percentages, the distribution among townships of the total number of forest fire outbreaks which occurred in 1963 through 1968. As can be seen, most of the outbreaks occurred in the Sandilands Provincial Forest. This area consists of droughty sandy soils on which jack pine predominates.

Outbreaks of fire were also relatively numerous in the townships east of the Sandilands Forest and adjacent to the international border. Soils are heavier and wetter here and deciduous species more numerous. On the other hand this area is more densely populated and areas of farmland are interspersed with forest so that causes of fire are increased.



Map 1. South East Forest Area, Manitoba, 1969.



Map 2. Distribution of Forest Fire Occurrences by Township, South East Forest Area, 1963-1968.

The northeast part--just under half of the area--has been almost free of fires. This part consists of heavy soils with many swampy areas, and is relatively uninhabited and non-agricultural.

Conservation officers' headquarters and fire towers are shown on Map 3. The system of towers provides almost complete coverage assuming a 12 mile radius of visibility, and towers are closer together in areas subject to more frequent fires.[1] Also, the protection plan (see Appendix 1) which is in use calls for greater preparedness in areas of higher fire occurrence.

Based on the above observations, it was concluded that analyzing possible relocations of personnel to increase efficiency in the South East Area did not appear to be a problem of great urgency, and could not be done properly without an in-depth study which might not be economically justifiable.[2] Attention was therefore concentrated on factors affecting the rate of spread of fires and the degree of success achieved in their suppression, and on how suppression should be evaluated economically.

Area Burned per Fire

1. Environmental Factors:

Data were obtained from fire reports and meteorological stations for the years 1963 through 1968 and regressions run to investigate relationships between rate of spread and possible causal factors.

Results indicated that, as expected, the rate of spread between time of detection and time of attack was lower in fires which occurred within six days after precipitation, was greater at higher temperatures, and was increased by wind.[3] Unfortunately there was too much unexplained variation in rates of spread for reliable estimates to be made of the effects of rain, temperature and wind. This unexplained variation may be due to variation in accuracy of reporting fires and differences in fuel types and conditions.

2. Suppression Factors:

Rate of spread varies considerably during the life of most fires. It was therefore not surprising to find that only a small percentage of variation in the average rate of spread during suppression could be

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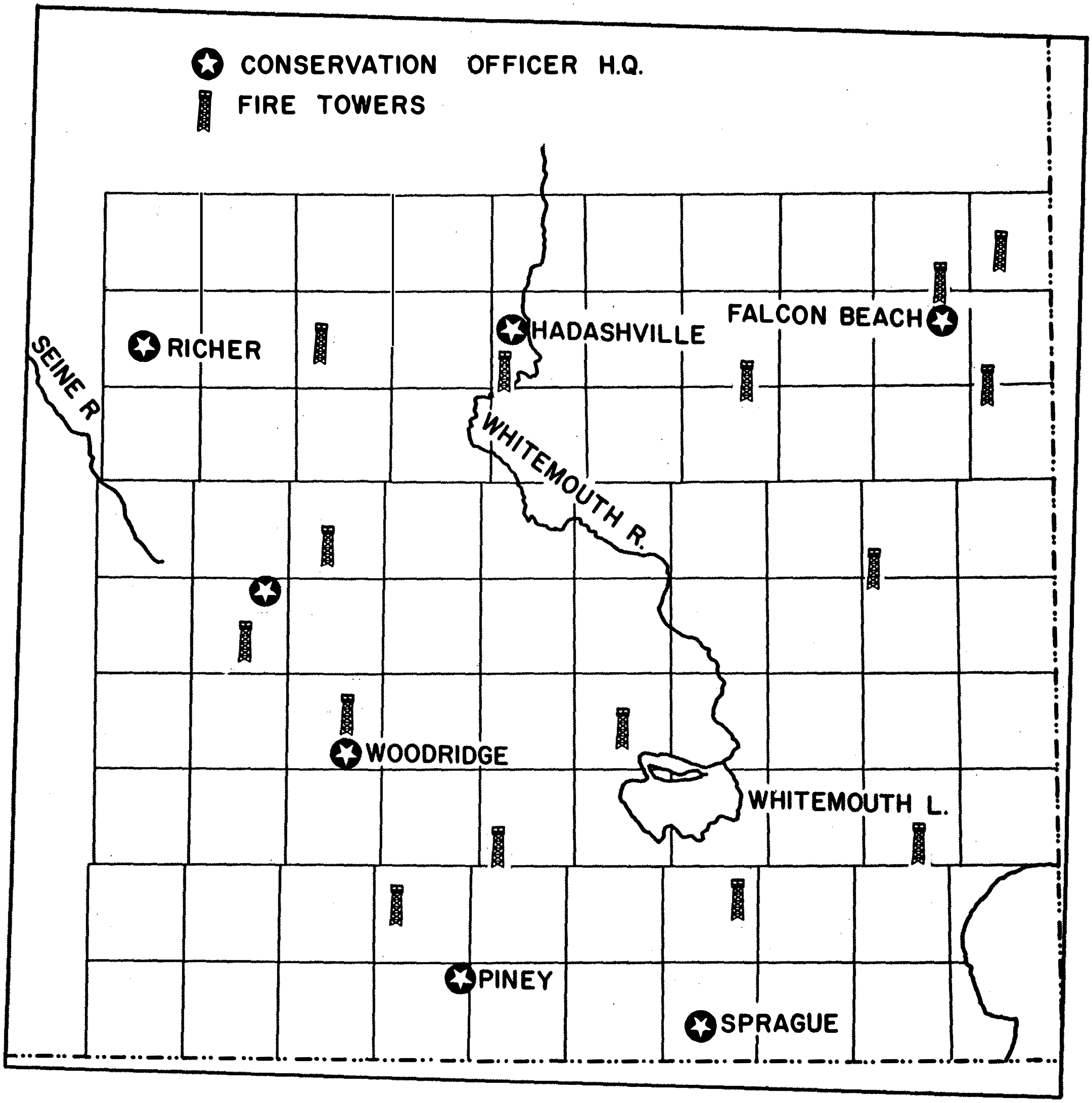
[1] See Jeffrey, C.A. 1967. A study of the tower detection system potential of the Southern Region, Bulletin No. 10, Manitoba Forest Protection Division.

[2] For further discussion of the problem, see Kourtz, P.H. and W.G. O'Regan. 1968. "A cost-effectiveness analysis of simulated forest fire detection systems", Hilgardia, 39(12): 341-366.

[3] Similar correlations were found by Fahnestock, G.R. 1965. Texas Forest Fires: in relation to weather and other factors, Research Paper No. SO-16, U.S. Forest Service.



Map 3. Conservation Officers' Headquarters and Fire Towers, South East Forest Area, 1969.

explained by multiple regression on possible causal factors. More surprising, and satisfying, were the results obtained when area burned, rather than rate of spread, was made the dependent variable.

The sample analyzed included 60 fires of one acre or more at time of attack which occurred in the South East Area in 1963 through 1968.[4] Results of regressions which were run are shown in Appendix 2. Many factors change over time, including suppression management, equipment, accessibility, and volumes of fuel. To take this into account, it was decided that three regressions might be useful. The regressions run were 1) all years, 2) 1963 and 1964, and 3) 1967 and 1968.

The main conclusions reached are as follows:

1. For each additional acre allowed to burn before suppression was begun, the total area burned was increased by 1.3 acres, i.e., an additional 0.3 acres was burned during the suppression operation.

2. The addition of extra men to the first suppression crew was shown to be effective in reducing the total area burned.

3. There is evidence that the effects of additional suppression forces differed among fires of different sizes. The reduction in area burned per man per acre in the first suppression crew appears to have been considerably greater in fires which were larger at the start of suppression. However, further research is needed before this can be regarded as more than a tentative conclusion.

4. It was not possible to show a statistically significant effect on area burned due to adding men to the suppression force later on during the suppression operation. This was due to the absence of information about the area burned when the additional men began and ended their work.

5. It was not possible to analyse statistically the effectiveness of alternative hand tools (shovels, pulaski tools, axes and pack pumps) because of insufficient variation, for purposes of analysis, between fires in the combinations of tools used.

6. It was not possible to make a satisfactory analysis of the results from using plows. This was because plows have not usually been put to use until after the start of suppression, and data have not been kept on area burned at the start of plowing.

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[4] "Spot" fires (less than 1 acre at time of control) were the only fires excluded from the analysis. There were, in total, 163 fires reported during the period analyzed.

ANALYSIS AND CONCLUSIONS

Efficiency Criteria

Decision makers formulating fire control policy have before them a large number of possible alternatives. The more significant areas in which choices must be made are in the numbers and locations of personnel performing various tasks, and in the numbers and locations of pieces of equipment of various types. For example, detection may be carried out using towers or aircraft, or a combination of both. Suppression may consist of a ground operation or an aerial attack. Equipment for suppression may include a variety of hand tools and/or power machines.

The overall efficiency criterion for deciding among alternatives is minimization of cost plus loss.[5] However, this criterion is too far removed from the problems of daily administration to be of much value to firefighters. It would be more relevant to the majority of decision makers in a firefighting agency to have a criterion for sub-optimising, i.e., attaining the best possible results with a given budget. The task of deciding the aggregate fire control budget would be the responsibility of the legislative and senior administration. Minimum cost-plus-loss might be used for this decision if efficiency were the criterion. Problems of achieving the best results on whatever budget was considered optimum would be the responsibility of lower echelon decision-makers throughout the fire control agency. If efficiency were the criterion, the goal would be to minimize loss for the given budget. Loss would be minimized if men and equipment were hired, located, and employed in such a way as to equalize the reduction in loss per marginal dollar invested in all alternatives. The change in loss per marginal dollar will be referred to as marginal burn in the discussion which follows.

Rate of Spread and Marginal Burn

The most critical need for estimating marginal burn is knowledge about rates of spread of fires and of how rates of spread respond to suppression inputs. To estimate area burned because of delays before beginning suppression we need an estimate of rate of spread at the appropriate stage in the life of the fire. Using fire reports, it is possible to make an estimate (a) of average rate before suppression starts, and an estimate (b) of average rate during suppression. For several reasons, neither estimate is very good for our purposes. Estimate (a) is likely too low since rate of spread accelerates as the

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[5] The "least-cost-plus-damage" approach has a long history. See Davis, K.P. *et al.* 1959. *Forest fire control and use*, McGraw-Hill, New York, Chapter 17.

fire builds up.[6] Estimate (b) is also likely to be too low since rate of spread is decreased before control is achieved. However, estimate (a) could have either an upward or a downward bias if good estimates were not made of the time and area burned at discovery of the fire.

Banks and Frayer[7] analysed rates of perimeter increase between discovery and attack for 1,589 fires in the Eastern Region of the U.S. The rates of perimeter increase they reported are not readily comparable with the rates of area increase observed in the South East Area of Manitoba. To make a good comparison it would be necessary to know the areas of fires studied by Banks and Frayer, as well as to make assumptions about the usual shape of fires (see Appendix 3). Assuming, however, that the above U.S. fires were between 5 and 10 acres, it appears the Manitoba fires spread somewhat more rapidly. This may have been due to the inclusion of more grass areas in the Manitoba fires. Both sets of fire data indicated a more rapid spread in grass than in timber.

The estimated average rate of spread between discovery and attack for fires in the South East Area during 1963-1968 was approximately 7 acres per hour. Based on this, and on Banks and Frayer's findings, it is thought that a good estimate of the rate in woodland, as opposed to grass, at the time of beginning suppression would be approximately 6 acres per hour. This rate has been used in calculations below.

Location of Base and Area Burned During Travel Time

Given a rate of spread, it is easy to estimate the effect on burn of alternative distances from the suppression workers' base to the fire, as well as the effect of alternative travel speeds. Table 1 shows some results of this estimate assuming a rate of fire spread of 6 acres/hr.

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[6] Emmons, H. 1963. "Fire in the Forest", in Air, Space and Instruments (S. Lees, ed.), New York, McGraw-Hill, provides a theory of this well-known phenomenon.

[7] Banks, W.G. and H.C. Frayer. "Rate of Forest Fire Spread and Resistance to Control in the Fuel Types of the Eastern Region". Fire Control Notes, Volume 27, No. 2: 10-13.

Table 1. Area burned during travel to the fire: Effect of travel speed and distance between firefighter's base and fire (assuming rate of spread = 6 acres/hour).

Speed of travel	Area burned per mile of distance between base and fire
m. p. h.	acres/mile
15	0.40
20	0.30
25	0.24
30	0.20
35	0.17
40	0.15

Table 1 may be refined to take account of the estimated effect on area burned due to delays in starting suppression. Based on the regressions shown in Appendix 2, it was concluded that the area burned during suppression was increased by 0.3 acres for each additional acre burned before the start of suppression.[8] Thus, for each additional acre burned before suppression was begun, 1.3 acres was added to the total burn. Table 2 is similar to Table 1 except that this has been taken into account.

[8] This is an average derived from the 1963-64, and 1967-68 regressions. Since the variables used were in logs it was necessary to obtain an arithmetic equivalent of the estimated effects. This was done, and the estimate, 0.3 acres, obtained by finding differences between antilogs of products of the relevant coefficients and logs of areas at start of suppression, the latter being assumed to be average areas, plus and minus 0.5 acres, of the 1963-64, and 1967-68 fires.

Table 2. Travel speed, distance of fire from base, and burn.

Speed of travel	Additional burn per mile between base and fire
m. p. h.	acres/mile
15	0.48
20	0.36
25	0.29
30	0.24
35	0.20
40	0.18

Additional Firefighters

In the regressions (Appendix 2), fires were stratified by size at time of attack into three groups—1 to 5 acres, 6 to 10 acres, and 11 to 30 acres. Estimates were made of reductions in area burned due to adding men to the first suppression crew. Results indicated that adding another man per acre produced a greater reduction in area burned in larger fires than in smaller ones. More specifically, in the 1 to 5 acre fires, no statistical relationship was found between men per acre and area burned. In the 6 to 10 acre fires, results indicated that additional men per acre reduced area burned in some years. In the 11 to 30 acre fires, all regressions indicated that adding a man per acre to the crew produced a relatively large reduction in area burned.

In interpreting this, it should be noted, however, that crew size varied less than the area of fires, so that more men were sent per acre to fight smaller fires. The regression results illustrate the principle of diminishing marginal returns--the greater is the number of men per acre in the suppression operation, the smaller is the contribution which can be made by an additional man. We cannot be sure, however, using these data, whether the relationship between men per acre and area burned is the same for all sizes of fire, or whether it differs.

While better data and further analysis are required before firm conclusions can be reached, it does appear from these results that, unless it is very costly to adjust crew size, it would be more efficient to send smaller crews than has been the practice to small fires and larger crews to larger fires.[9]

The estimates of the coefficients which have been made must be regarded as highly tentative. The following discussion is therefore designed to illustrate some of the uses to which such estimates could be put rather than to provide planning data. If we consider the regression of Equation 1, Appendix 2, the coefficient for men per acre in fires 6 to 10 acres indicates that <u>adding one man per acre reduced area burned by 6 acres</u> (antilog 0.78). Since the average size of fire at time of attack was 7.2 acres (not shown in Appendix), it required the addition of 7.2 men to the crew to add 1 man per acre. If it is assumed that an additional firefighter costs $15 per fire, then it costs $108 to add one man per acre. This investment reduces area burned by 6 acres, therefore the marginal cost is $18 per acre and the <u>marginal burn is 0.06 acres per dollar</u>. As mentioned earlier, this return should be compared to returns from alternative ways of investing a dollar in the forest protection operation.

SUMMARY EVALUATION

Detection System

The South East Area already has a system of towers which allows complete visibility approximately 90 per cent of the time during all months from April through October.[10] The towers are spaced to permit almost complete visibility in clear weather. With rare exceptions, meteorological conditions are such that the use of aircraft would not provide better visibility than towers.[11] When the South East Area is considered as a separate detection unit, the present tower system appears to be more effective, under current costs, than a possible alternative of aerial surveillance without towers. However, if the South East Area could be combined with an adjacent forest area to form a larger detection unit, it might be possible to develop a more effective system consisting, perhaps, of some combination of towers and aerial surveillance. There is a need for further investigation of alternative systems, but the forest area included in the analysis should be larger than the South East Area.

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[9] Mr. A.J. Simard has pointed out to us the significance of uncertainty. Under present conditions, the area of a fire at detection can be known only vaguely. Therefore, in case the fire turns out to be unexpectedly large, it is considered good insurance always to send a big enough crew to deal with a moderate sized fire.

[10, 11] These are opinions based on 10 years visibility data of the Winnipeg International Airport weather station.

Suppression Forces

While the regression results are encouraging in view of the apparent complexity of the problem and crudity of the data, they are not powerful enough to form the basis for firm policy recommendations. Suppression forces, equipped with hand tools, have been shown to be effective in dealing with fire, and tentative estimates have been made of the area saved from burning per dollar invested in additional suppression forces. However, the estimates on effectiveness of mechanized suppression equipment were unsatisfactory, and it was not possible to estimate the relative effectiveness of alternative types of hand tools.

The main barrier to evaluation of several of the suppression inputs is the way in which fire reports are compiled. Hardly ever is any record kept of areas burned at intervals during the suppression operation. Hardly ever is any record kept of the times men and equipment are actually at work in suppression activities. In this study it has been assumed that all the men and equipment started work at the beginning of suppression and finished at the end. Most likely this assumption is incorrect and has led, through mis-specified variables, to biased estimates of regression coefficients. However, until such time as either the fire reports can be made more relevant for this purpose or an alternative source of data can be found, there is no basis for a better assumption about the duration of suppression inputs.

It is concluded, therefore, that there is a need for much more precise data collection on areas burned and men and equipment employed in suppression at frequent intervals during the life of the fire. If possible, data should also be collected on fuel types, terrain and meteorological conditions though, if resources are limited, this should be given a lower priority.

Subsequent dissemination of the data should be closely restricted in order to allow necessary experimentation and unavoidable small errors in strategy without causing embarrassment to suppression forces. Data collection and use should be planned in consultation with decision makers in suppression so as to obtain maximum benefit from their experience and to produce maximum co-operation.

Appendix 1

Regulations Included in District Detection Control Chart, South East Forest Area, Manitoba

Danger Index		Minimum Control
Low--Moderate	(1-4)	Towers manned when required.
Moderate--High	(5-8)	Seddon's, Contour, Westguard, Marchand, Halfway, Richer, East Braintree, Caribou, Wawa, Sprague, Badger and Woodridge (Menisino)* Towers manned from 11:00 a.m. to 6:00 p.m. DST. 10:00 a.m. to 6:00 p.m. DST.* All trucks equipped with a minimum of 5 pack pumps, 6 shovels and 2 axes.
High	(9-12)	Hadashville, Whitemouth Lake and Menisino towers manned in addition to the above from: 11:00 a.m. to 6:00 p.m. DST. 9:00 a.m. to 7:00 p.m. DST.* If winds exceed 15 m.p.h., the above towers manned from 10:00 a.m. to 7:00 p.m. If danger index is 10-12 with above winds, one man on patrol. Equip all wheel tractors and unimog with ploughs and/or tank trailers on stand-by 9:00 a.m. to 7:00 p.m.
Extreme	(13-16)	All towers manned from 10:00 a.m. to 7:00 p.m. (If winds in excess of 15 m.p.h., 10:00 to 8:00) Additional patrolmen assigned, crawler tractors loaded and standing-by. Burning permits cancelled when Danger index and Drought index both exceed 12.

* Emergency periods and May 1st to June 15th.

Appendix 2

Regressions of Area Burned During Suppression, South East Forest Area, Manitoba, 60 Fires, 1963–1968.

Dependent variable = log of area burned during suppression (log acres)

Independent variable[a]	Equation 1. 1963–1968, 60 fires		Equation 2. 1963, 1964, 25 fires		Equation 3. 1967, 1968, 25 fires		Means of variables: 1963, 1964	Means of variables: 1967, 1968
							Area burned during suppression	
	coefficient	standard deviation	coefficient	standard deviation	coefficient	standard deviation	4.2 acres	2.6 acres
Log of area at start of suppression (log acres)	0.894**	0.204	0.685*	0.267	0.457	0.403	4.2 acres	3.4 acres
Wind speed (m.p.h.)	0.021**	0.007	0.040*	0.019	0.011	0.010	11.1 m.p.h.	10.2 m.p.h.
Precipitation during 6 days preceeding fire (inches)	-0.544	0.281	-1.167*	0.431	-0.712	0.561	0.14 inches	0.07 inches
Extreme daily high temp.[b] (°F)	-0.001	0.005	-0.011	0.010	0.000	0.008	69.0 °F	67.0 °F
Men per acre in first suppression crew in:								
fires 1-5 acres	(36)[e] 0.039	0.033	(12)[e] -0.053	0.055	(17)[e] 0.079	0.044	3.050 men/acre	1.864 men/acre
fires 6-10 acres	(14)[e] -0.780**	0.249	(6)[e] -1.986**	0.564	(6)[e] 0.377	0.438	0.096 men/acre	0.125 men/acre
fires 11-30 acres	(10)[e] -3.868**	1.093	(7)[e] -5.765**	1.505	(2)[e] -5.716*	2.377	0.042 men/acre	0.016 men/acre
Men added to crew after start of suppression[c]	0.032	0.026	0.028	0.044	0.000	0.040	1.12 men	1.04 men
Plows per acre used in suppression in:								
fires 1-7 acres[d]	(18)[e] 0.040	0.167	(3)[e] 0.289	0.234	(12)[e] -0.111	0.304	1.047 plows/acre	0.564 plows/acre
fires 8-30 acres[d]	(7)[e] 7.959**	2.152	(5)[e] 13.114**	3.333	(2)[e] 22.769	13.068	0.021 plows/acre	0.004 plows/acre
Y intercept	-0.164		0.821		0.009			
R^2	0.706		0.896		0.785			

[a]Estimates of coefficients of variables footnoted b, c, and d are not considered interesting _per se_, but these variables have been included so as to obtain better estimates of the other variables.

[b]Temperature _at time and location of fire_ would be a more meaningful variable, but was not available. Data used are from nearest weather station.

[c]Area burned at time men started work is not known. Men _per acre at that time_ would be a more relevant variable.

[d]Area burned _at time plows were set to work_ is not known, so there is specification error in this variable.

[e]Number of observations is shown in parentheses.

*Coefficient differs significantly from zero at 5 per cent.

**Coefficient differs significantly from zero at 1 per cent.

Appendix 3

Rate of Spread: Change in Area Compared to Change in Perimeter of Fires

In order to compare the rate of spread in area of a fire to the increase in its perimeter, assumptions must be made about the shape of the fire.

If it is assumed that the shape of the fire is an ellipse with major axis = 2a and minor axis = 1.33a then, since

area of ellipse = πab, where a and b are semiaxes, and

perimeter of ellipse = $2\pi \frac{a^2 + b^2}{2}$, approximately,

area of fire = $A = 0.67\pi\ a^2$, and,

perimeter = $P = 1.70\pi\ a$.

The derivatives of these are:

$$\frac{\partial A}{\partial a} = 0.67\pi\ a, \text{ and}$$

$$\frac{\partial P}{\partial a} = 1.70\pi$$

Therefore, $\frac{\partial A}{\partial P} = 0.39a$.

In other words, under the assumptions which were made about the shape of the fire, the area increases by 0.39 times the major semiaxis for every 1 unit increase in the perimeter.

Reference tables such as that shown on the following page may be constructed using these results.

Table 3.1 Change in Area Corresponding to a Unit Change in Perimeter. (For assumptions, see text)

Area A		Major semiaxis $\sqrt{\frac{A}{.67\pi}}$	Change in area per unit Change in perimeter
Acres	Sq. chains	Chains	Sq. chains per chain
5	50	4.87	1.89
10	100	6.89	2.69
20	200	9.75	3.80
30	300	11.94	4.66

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