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by

J. S. MACTAVISH[2]

INTRODUCTION

Over the years considerable attention has been given to selection of goals for forest fire control. In North America the majority of these goals have been physical working objectives designed to guide fire control efforts on individual fires or over a fire season. These goals have usually been related to one or other of three parameters: fire size, time or annual losses. Fire-size objectives have included those based on maximum fire size, average fire size and percentages of fires allowed to become larger than specified sizes. Time objectives have been defined in terms of specific periods allowed for fire control, while annual loss objectives have included "acceptable" average annual burned area percentages. In addition to these general objectives bearing on the combined phases of fire control, specific targets have been developed for prevention, presuppression and suppression activities. Included in this category are prevention programs aimed at the elimination of particular fire causes, presuppression programs to ensure detection of all fires within specified time periods, speed of attack targets, and suppression standards defined in terms of rates of fire line construction. While such guides have proved useful, they all suffer from the same defect in that their economic implications are unknown or uncertain.

The programs of forest management, like those of any other business, are gauged in terms of money, and business planning is usually presumed to be based on the criterion of maximizing wealth. Forest protection planning, as the first stage of forest management, should be described and justified in terms of gains and losses expressed in monetary terms to the furthest extent possible. Only in this way can it be determined whether or not the physical goals of fire control are adequate or perhaps even excessive.

The economics of forestry is sometimes considered to be a rather special or distinctive discipline, but there is nothing novel or mysterious about the minimum-cost-plus-loss criterion for fire control, at least as far as the economic principles go. It is the same basic tool used for planning business and government endeavours and called variously marginal or benefit-cost analysis. The only difference, and it is not a real difference, is that the benefits received from fire control are measured as reductions in losses rather than increases in net revenues. If it can be assumed that marginal analysis techniques are sound for other business enterprises, then the identity of the minimum-cost-plus-loss technique with marginal analysis should dispel any criticisms as to the theoretical soundness of the concept for fire control planning. Not only should it be useful for determining the optimum level of forest fire control, but it should be equally useful for planning division of fire control budgets among the three principal functions, prevention, presuppression and suppression, as well as for planning particular projects within a function.

The economic minimum-cost-plus-loss objective for forest fire control has

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already been outlined in a minute of the Secretariat (Anon. 1959). The object is to increase expenditures until the last amount spent on prevention and presuppression (including detection) is just matched by an equal reduction in the total of damage and suppression costs. Suppression costs are included with damages on the "output" side of the equation since both vary inversely with prevention and presuppression costs.

The most straightforward, but still difficult, approach to the estimation of fire control standards would be to attempt to find the influence of average annual prevention and presuppression expenditures on the average annual total of damage and suppression costs and plot the totals of cost-plus-loss over the prevention and presuppression costs. The minimum point of cost-plus-loss would then indicate the most economic level of prevention and presuppression input. This approach was used by Craig *et al.* (1945, 1946a, 1946b) in the United States in a series of studies that still stands as one of the most interesting attempts to apply economics to fire control planning. Very briefly, they attempted to estimate the effects of average annual area burned on the values of timber, watersheds, wildlife, recreation and grazing in several regions of the southern United States. They even attempted to estimate the indirect influences of the average annual timber losses on the regional economy by estimating the impact of the lost timber volume on future industrial incomes, income payments and tax payments. Since data for the individual study regions did not cover a sufficiently wide range of costs, a master curve relating area burned to costs of fire control was prepared with data from a number of regions. To improve the relationship between burned area and costs of control the data from the various regions and years were adjusted for the changing purchasing power of money, area receiving protection, length and severity of fire season, and numbers of fires. The master curve was then adapted to each study region and current damage and suppression cost values were substituted for area burned as the dependent variable. Summation of the damage plus suppression cost function with corresponding prevention and presuppression costs yielded a point of least-cost-plus-loss per unit area.

The most recently published approach to the problem of fire control standards in Canada was presented by Beall (1949). He found that although the least-cost-plus-loss theory had much to commend it, knowledge of the factors involved was not adequate to permit specification of practical objectives in such terms. (Unfortunately, this statement may be equally applicable fifteen years later). Beall based his standards on an acceptable area burned criterion on the assumption that there must be some average annual burn percentage that would correspond to the point of minimum-cost-plus-loss. On this assumption he first selected an acceptable average annual burning rate for one particularly valuable and vulnerable timber type. The basic rate, one-tenth of one per cent, was established after consultation with natural resource experts. Acceptable burning rates in other forest types were related to this standard by first dividing the forest area of the country into more or less homogenous zones based on forest classification, productivity, accessibility, lightning risk, climate and topography. Within each zone acceptable burned area values were related to the base value with the aid of a formula that included factors for: productivity and values for wood, streamflow regulation, recreation and wildlife; destructibility or completeness of potential damage to forest and site values; ease of stand re-establishment after fire; fuel hazards before and after fire; lightning risk; accessibility, climate and topography. The most serious criticism of the method was that lack of data dictated use of subjective reasoning. Still, the method has remained as the major guide for fire control planning in Canada.

A MODEL APPROACH

To date in Canada the conventional wisdom of economics has proved remarkably sterile for fire control planning. This seems to have resulted from three basic causes: lack of data; lack of analysis technique; and lack of interest. The third cause can be dismissed, since surely it stems from previous frustrated attempts to solve the problem. The second cause, lack of technique, is really a lack of technique to fit the types and amounts of data available. The key to the problem seems to be the lack of data with which to work, and the array of variables involved. Possibly an understanding of previous failures, and an indication of the problems to be solved and the kinds of data required to do so may be found by looking to some other field where benefit-cost analyses have been applied more fruitfully.

On first examination, at least, flood control project planning seems akin to fire control planning. The benefits received from each are primarily in the form of loss reductions. The weather has crucial, if opposite, effects on each. The activities of man on the land vegetative cover may have strong and sudden influences on each, in the one case creating more hazardous fuel types and in the other, allowing more rapid runoff and erosion. Fire prevention programs may be considered similar in purpose to dam construction, the first reducing fire-occurrence rates and the second reducing peak streamflow rates. Presuppression efforts are directed at minimizing the losses from fires that the prevention programs do not affect, while channel improvements are undertaken to contain unusual streamflows that the dams are unable to contain.

In the following comparison of greatly simplified flood and fire control planning techniques, the emphasis is placed on points of difference and difficulty for fire control planning, and on the kinds of data required to make economic fire control planning feasible. No pretence is made to solve the planning problem from statistical or economic points of view, only to outline a possible solution.

A standard flood control planning criterion is the maximization of expected average annual returns, consisting mainly of decreased flood damages, but also including increased down-stream values consequent to reduced flood hazard. The first concern of the flood control planner is to learn something of the probabilities of occurrence of floods of different dimensions, and of the resultant damages. The first step is to prepare a frequency function for peak rates of flow from recorded streamflow data. Sometimes it may be necessary to extrapolate the flow-frequency curve, or to employ simulation techniques to artificially increase the amount of historical data to produce a useful function. Since the data are of a time-series nature, particular attention must be paid to physical changes that might have occurred in the watershed, and to how these changes have influenced the flood inhibiting characteristics of the land.

With a peak streamflow frequency function prepared, the next step would be to relate the streamflow rates to flood stages, the amounts by which stream banks are exceeded, and through flood stages to flood areas and depths, which are dependent on the valley configurations. Past flood records, sometimes augmented with records adapted from other drainage basins provide the necessary data. Estimations of possible damages to be expected from various floods may then be developed by relating surveys of damageable valley properties to the flood stage-inundation area relationship.

To this point the flood and fire control planning task seem remarkably similar, but there are some important differences. At first glance it might appear that rate of fire spread might be used analogously to rate of streamflow in developing a frequency function, but rates of fire spread will differ considerably among fuel types and seasons for the same consequent damages. Even if some average rate of spread were calculated it would remain an incomplete factor for fire control planning. Fire losses and suppression costs are related both to rate of spread and resistance to control. Perhaps some measure of fire intensity would serve as a variable more closely related to costs and damages. Byram (1959) discussed a fire intensity formula that might serve the purpose. In this formula fire intensity is measured as the product of linear rate of spread, the heat of combustion, and the weight of fuel consumed. It includes factors influencing both costs and damages, a desirable feature, but a little consideration will show that even the fire intensity factor will not be as closely related to the fire control problem as peak streamflow is to that of flood control.

While a particular valley may be expected to suffer one flood at a time, there may be several concurrent fires in a similar water-shed. The number of concurrent fires may be just as important as the fire intensities of individual fires. Perhaps the two factors could be combined into a single variable of total fire intensity, hereafter referred to as fire load. This would be a powerful factor embodying three elements critical to fire control—rate of spread, resistance to control and rate of fire occurrence. In addition the two components of the fire load variable should be relatively easy to determine. Fire intensities may be found experimentally and related to existing fire danger rating systems or to weather elements, while numbers of fires should be the most readily available fire statistic.

The fire load factor does present certain difficulties, the first being time. What time period should be used for determining the number of concurrent fires? Since the degree of success in fire control is closely related to the initial fire control action, including the time elapsing between ignition and commencement of fire fighting as well as the size of initial attack, it would seem logical to use one day as the unit of time. The number of simultaneous fires could be taken as the number of fire starts on one day, while fire intensities could be measured at the peak burning period of the day. The main difficulty with the time element, however, is that some fires, especially the most damaging ones at extreme levels of fire danger, burn over periods of days or even weeks. Thus the fire control costs and damages from a group of fires starting on one day at a given level of fire intensity will depend to some extent on fire occurrences and intensities of the immediately previous days or weeks, depending on the strength of the fire control organization. In addition, the correlation between peak fire intensity, as measured at the most hazardous period of the day of ignition, and costs and losses will tend to decrease as the burning period lengthens over days of differing weather conditions. The more highly developed the organization, however, the fewer would be the occasions when fires would remain uncontrolled for more than a day; and if the assumption is made that the most economical fire control will dictate prompt attack and control, the above criticisms should not distract from use of the daily fire load factor in planning.

Again, by combining fire intensity and numbers of concurrent fires into a fire load index, it might be found that a number of days could exhibit the same fire load but differ considerably for damages and/or suppression costs absorbed. Several fires, combined with the fire intensity to be expected on a day of "High" fire danger, might yield the same fire load factor as a single fire occurring on a day of "Extreme" danger. However, the probabilities of this happening might be of little significance since the concurrent fire variable should exhibit a strong positive correlation with the fire intensity variable.

The fire control planner is confronted with an obstacle the flood control planner need not face. While man's use of the land can indirectly influence both the numbers and severity of both floods and fires, this can be allowed for in an analysis; but climatic conditions alone act as a direct cause of floods. The fire control planner must deal with two direct causes, lightning and man. The significance of this is that the influence of one fire control variable, prevention, is included in the basic fire occurrence data. Multiple regression techniques might prove useful in indicating the net effects of prevention in the presence of changing forest-use patterns, but several obstacles stand in the way. In addition to data on total expenditures, the analysis requires data on the effects of the changing content of fire prevention programs. Any unmeasured change in the effectiveness of the prevention dollar would contribute to the error of the analysis. Indeed, it will be difficult enough to determine gross prevention expenditures from accounts. The costs of some measures, particularly closure of the forests to industrial and recreational use, will be particularly illusive since they involve indirect costs to the people affected as well as the direct costs of enforcement. Accounting procedures are often devised seemingly to thwart the efforts of research, with costs of fire prevention hidden amongst other charges.

Treating the forest-use variable in the analysis will be perplexing. Indices might be developed from records of visits to public parks and woods labour employment, for example, but the relationships between such indices and fire occurrence are likely to be weak considering the number of reasons for man-caused fires and the number of ways these fires may be ignited. Causes and ignition agents have been changing in both kind and importance. For example, a new category of industrially caused fires appeared in Canada with the advent of the power saw. The numbers of incendiary fires decreased as the standard of living improved in rural areas. The number of fires caused by the railways decreased sharply with the introduction of the diesel locomotive. The most promising approach to estimating the effects of prevention campaigns on the one hand and increasing forest use on the other may be a step by step analysis of individual causes and ignition agents and the prevention efforts expended against them.

Changes in the purchasing power of money must be allowed for. Since fire seasons differ both as to length and severity, data on fire danger or fire intensity levels as computed from weather records would be required. Length of fire season may be important where fire prevention budgets are fixed on an annual basis. Duration of periods of hazardous weather may be an important variable influencing public response to prevention programs.

Considering all these complications, estimation of the consequences of fire prevention outlays on frequencies of various man-caused fire occurrence rates at different fire intensity levels will not be nearly as straightforward as the development of flood frequency functions. If it is found necessary to ignore the historical effects of fire prevention or to estimate them subjectively, expected fire load occurrence frequencies based on historical data may be high or low depending on whether the prevention outlay or forest-use factor has been dominant. In any event, the counterpart of the flood control planner's flood frequency function would be a fire-intensity-frequency-function depicting the occurrence probabilities of different fire intensity class days, and for each fire intensity class, a frequency function of fire occurrence rates per day. (Figures 1 and 2). From the two, expected frequencies of fire loads could be determined.

By this stage it is already apparent that the successful application of flood control planning techniques to forest fire control will require extensive fire histories relating to a wide number of factors. Much of the required information probably is not now available; still, it is worthwhile to carry the model development through to gain at least a little more insight into the complexities of fire control and the kinds of data required.

With the development of basic flood and damage frequency curves, the flood control planner proceeds to the input side of the problem. Engineering data yield the capital costs of dams of various types and capacities. These data, together with records of past flood hydrographs along with flood routing assumptions, can be used to determine capacities of dams required to reduce peak flows by specified amounts. Since flood hydrographs differ, it is often necessary to repeat the procedure for floods of several probabilities of occurrence to estimate dam capacities and costs required to reduce expected streamflows by specific amounts. Further, past records enable the planner to estimate the maximum streamflows to be expected below designed dams of various capacities. Engineering data can then be employed to estimate costs of improving downstream channels to carry the expected flows, one curve for all floods. Thus, for the control of floods of each of the selected probabilities of occurrence, one cost curve is developed to show the cost of reducing the expected peak flow to various levels and a second curve describes the cost of channel improvements to handle the remaining flow. Summation of the two curves yields a total cost curve for elimination of floods of a selected probability of occurrence, the minimum point on the curve being the most economic combination of dam capacities and channel improvements. Lastly, the minimum cost points for the several floods sizes of selected probabilities are plotted against flood damage reductions expected from complete control of these floods, and the economic optimum flood control program is indicated by the point at which benefits exceed costs by the maximum amount.

Some of the difficulties involved in the estimation of the effectiveness of fire prevention expenditures, the counterpart of dam construction, have already been outlined. Further consideration will be reserved for the moment. But what of presuppression costs, those costs that might be considered analogous to stream channel improvements? The aim of the presuppression program is to ensure prompt containment of the fires expected in spite of the fire prevention campaign. Speed is of the essence, particularly at the higher levels of fire danger. Forty years ago, Sparhawk (1925) demonstrated that the time permitted to elapse between the discovery of fires and the instigation of fire fighting has a marked influence on the eventual area burned and, of course, on the consequent damages. Fire fighting costs in turn are closely related to area burned and thereby to the elapsed time variable. Arnold (1950) considered the elapsed time factor to be so important that he developed a model for economic fire control planning around it.

But elapsed time between fire discovery and the beginning of fire fighting could be improved upon as an index of presuppression intensity. The most obvious improvement, which Sparhawk recognized but had no data for, would be to measure elasped time from the time of fire ignition, rather than discovery, to the time fire fighting began. Only in this way can the intensity of fire detection, one of the major elements of a presuppression organization, be taken into account. The estimation of elapsed time between ignition and discovery requires development of data relating to fire size on discovery, and rate of spread characteristics for the various fuel types over the range of fire danger. These data may be acquired both by study of experimental fires and observations made on uncontrolled sectors of wild fires.

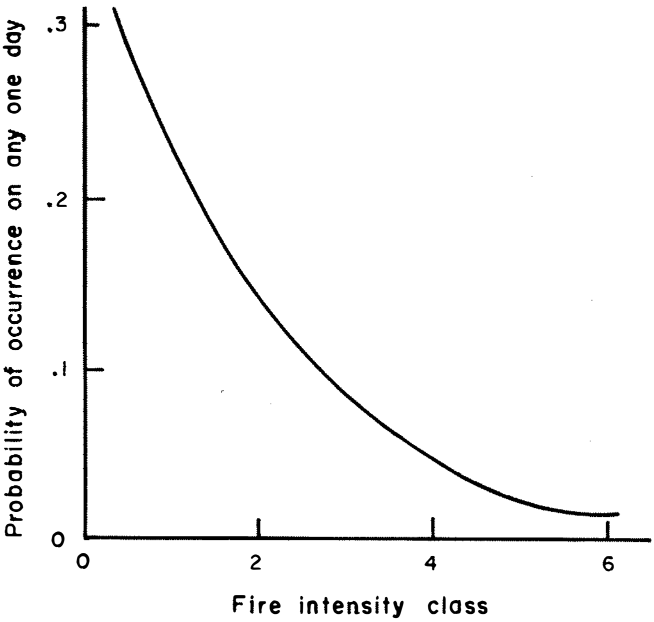

FIGURE 1. Fire intensity class frequency function.

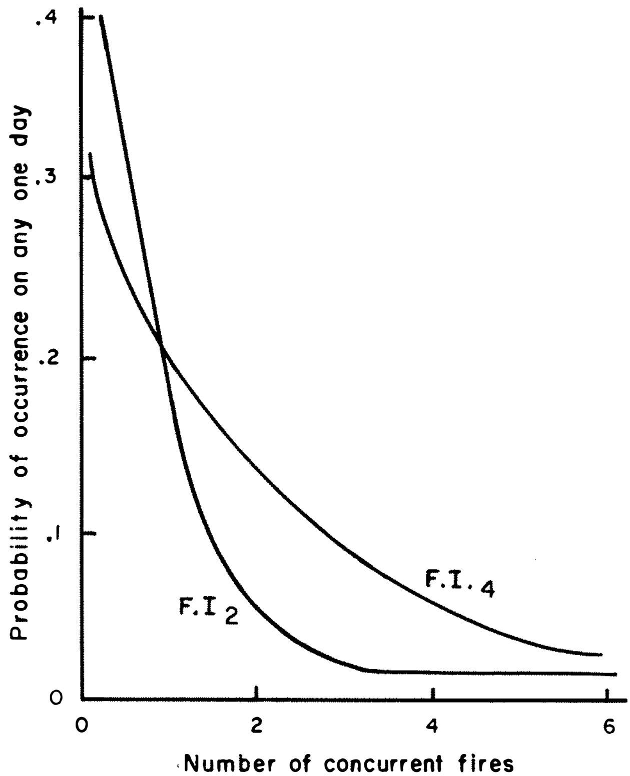

FIGURE 2. Frequency function of numbers of concurrent fires per day of fire intensity class.

Still, as Arnold's model partially allowed for, even the total elapsed time factor is an incomplete gauge of presuppression intensity. As important is the size and content of the initial attack, and the ability to back this up with additional men and equipment as required. The initial attack can vary as to number of men and the amount and type of equipment used. Ideally, physical data should be developed to rate various pieces of equipment such as pumps, tractors and aircraft in terms of known output of a single factor such as a man with hand tools. Unfortunately, these relationships will change with a number of factors including fuel type, soil, topography, proximity of water supplies, and particularly fire intensity. Depending upon the variations in these factors in the study area it may be possible to produce useful ratings in terms of manpower; however, it is unlikely that many such basic studies have been carried out in most countries.

Were ratings available for various types of fire fighting equipment in terms of numbers of fire fighters, or some other variable, at given levels of fire intensity, then following Arnold's (1950) model, it should be possible to develop sets of curves, one for each selected fire intensity level, to show the total damage + suppression costs for individual fires related to size of fire fighting crews and elapsed times (Figure 3). The minimum points on the damage + suppression cost curves would indicate the optimum crew sizes for the range of attack times. The minimum points of damage + suppression cost could then be replotted over elapsed time as the independent variable to produce a regression of minimum damage + suppression costs on elapsed time (Figure 4). A series of such minimum-cost-loss curves could be prepared from records of past forest fires, one curve for each of these selected fire intensity levels. (The problems of damage appraisal will be touched on below).

This approach presupposes control of forest fires by the initial attack forces. Experience in Canada has shown, however, that if fires of potentially high intensity are not contained promptly the chances of control in the absence of precipitation are sharply limited; consequently, the size of initial attack should be closely related to damage + suppression costs at their minimum point. The fact that correlations between variables may not turn out to be of the highest order, should not inhibit completion of the analysis or trial application of the results. Unlike the dam builder whose dam may be a lasting monument to his genius or a continual reminder of his monumental error, forest fire control plans are flexible permitting annual modifications as new information comes to light. Considering the undeveloped state of economic fire control planning, in Canada at least, the answers need not be precise, just as long as they guide the fire control organization in the right direction.

With a series of curves relating expected minimum damage + suppression costs to elapsed time at each of several fire intensity levels, the next step would be to determine the annual presuppression costs per unit area required to place crews of the optimum size on fires within the elapsed time prescribed to produce minimum damage and suppression costs. Unfortunately, more than one such presuppression cost curve would be required for each of the selected levels of fire intensity, for, at this point the second element of the fire load index, the number or concurrent fires enters the problem. The number of expected concurrent fires will influence presuppression costs for equipment and manpower and may affect the numbers and/or locations of fire control depots, and the types of transportation to be used. Often it is the number of concurrent fires that is the prime factor leading to the breakdown of fire control organizations.

Development of a set of hypothetical presuppression cost curves really involves a separate group of problems in fire detection, transportation and control logistics,

FIRE INTENSITY CLASS 3

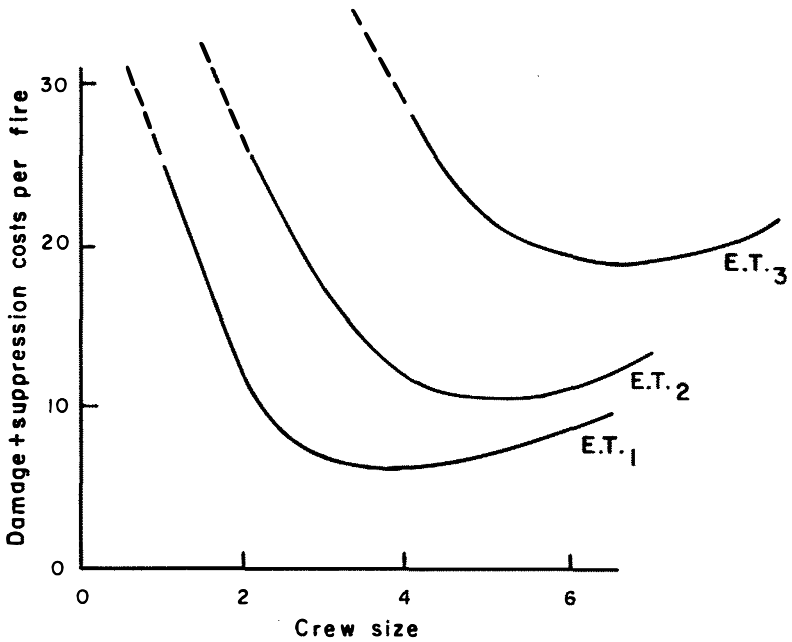

FIGURE 3. Damage + suppression costs related to elapsed time and size of initial attack.

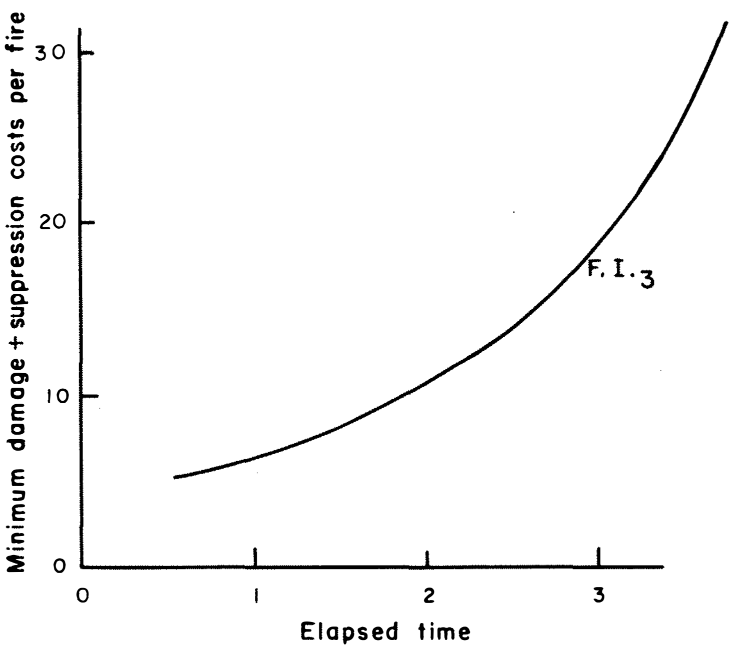

FIGURE 4. Minimum damage + suppression cost per fire related to fire intensity and elapsed time.

and suppression techniques, answers to which, like those for stream channel improvements, should be known before attempts are made to develop useful economic standards. Data would be required on where and when fires start so that the most efficient number and spacing of fire control units and the optimum numbers of crews per unit could be estimated. How will various means of transportation and types of fire fighting equipment influence the number and spacing of units? Which arrangement of depots and transportation systems permit initial attack within the prescribed elapsed times at minimum cost? How has the total elapsed time been divided between detection time and attack time? Where is the break even point between improving fire detection facilities and the attack organization? The list of such questions, many of which have received little formal analysis in Canada, is long. Still, it may be possible to develop reasonably reliable sets of hypothetical presuppression cost curves, one set for each of the selected levels of fire load (Figure 5), based on recorded past experiences.

Within each fire intensity level the optimum elapsed time and corresponding presuppression organization for each expected fire load (fire intensity × number of fires, $F.I._x f_x$) is found by combining the curve of minimum damage + suppression costs (Figure 4) with the appropriate presuppression cost curve (Figure 5) as shown in Figure 6. But these optimum elapsed times, with corresponding expected minimum total damage and suppression costs and the optimum presuppression expenditures apply only to particular fire loads and do not account for what the presuppression organizations may be expected to accomplish on fires of higher or lower fire intensity class than that for which the model is drawn.

As the flood control planner carries out his analysis for control of successively larger floods with bigger dams and stream-channel improvements, he can assume complete control of all smaller floods. The fire control planner, on the other hand, can only plan on minimizing the sum of fire damage and suppression costs, and this minimum at each fire intensity level will change with successive increases in planned fire control as these increases permit shorter elapsed times and/or more efficient crews. Therefore, the curve of minimum damage + suppression costs must not be for a single fire at the fire intensity level for which presuppression costs are being studied, as in Figure 6, but must be a composite curve for all fire loads based on their probabilities of occurrence, each point on the curve being a weighted expected damage + suppression costs for fires of all fire load levels. At each level of fire load planning, it will be necessary to examine the makeup of the planned presuppression organization as developed for Figure 5 to meet the requirements of minimized damage + suppression costs of Figure 3. For each elapsed time interval a specific organization for detection, transportation, and size of initial attack will have been planned. The problem is to estimate the effects of these planned organizations on both lower and higher fire loads.

It is logical to assume that the fires of fire loads lower than that being planned for will be controlled promptly with the more than adequate fire control force. Minimized damage + suppression costs per fire expected to result at the lower fire load with specific levels of the planned presuppression force (Figure 5) may be estimated from the sets of minimum loss curves (Figure 3). The product of the minimum loss per fire from Figure 3, the number of concurrent fires within the fire load, and its probability of occurrence from Figures 1 and 2 will yield an estimate of losses to be expected from the lower fire load in spite of the planned presuppression level.

For fire loads much above the load being planned for, it would be possible to assume lack of "planned" control, that is, there would be no control by the initial

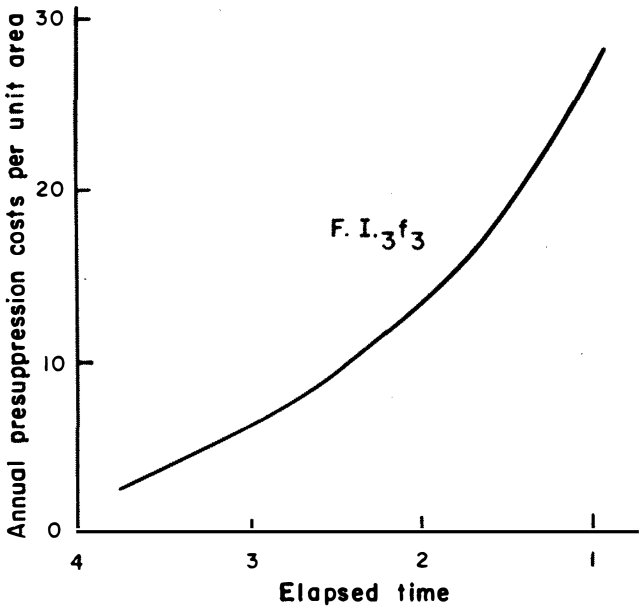

FIGURE 5. Average annual presuppression costs per unit area required to ensure minimized damage + suppression costs up to a specified fire load.

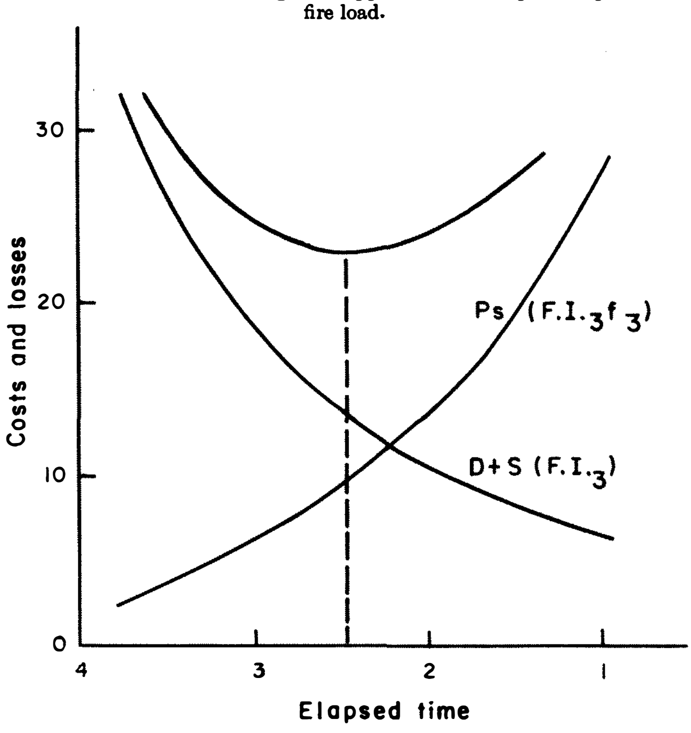

FIGURE 6. Least-cost-plus-loss combination for a specific fire load.

suppression action, final control depending on a weather-caused reduction in fire intensity sufficient to permit the suppression forces to gain the upper hand, or on extensive use of emergency suppression forces. Expected burned areas for these fires would have to be estimated from past records of escaped fires to which current per acre loss and suppression cost estimates could be applied. Expected losses from these higher-than-planned-for fire loads would not alter the slope of the damage + suppression cost curve, and consequently not alter the optimum level of presuppression organization at the particular fire load level being planned for. On the other hand, the losses from escaped fires would raise the total amount of cost-plus-loss at the presuppression planning level. The importance of this will become apparent shortly.

It is difficult to estimate the effect of a given presuppression organization on fire loads only slightly above the loads that the organization is designed to control with minimized damage + suppression costs. If historical records do not yield satisfactory indications of the effects of specific sub-optimum presuppression organizations, it may be reasonable to assume, partly as a safety factor, that all fires beyond those planned fire loads will escape initial control action. For example, if the presuppression organization were planned to achieve minimized damage + suppression costs at a fire load of fire intensity class three with three concurrent fires ($F.I._3f_3$), one fire would be expected to escape if fire load $F.I._3f_4$ occurred. Damage and suppression costs for the "extra" fire would then be assumed unrelated to the presuppression cost level.

From the above considerations a probability weighted damage + suppression cost function may be estimated in relation to the range of presuppression costs (from Figure 5) for the specified fire load. Combination of this function with the corresponding presuppression costs will yield a point of minimum cost plus loss for the fire load planning level (Figure 7). Similarly, other minimum-cost-plus-loss points may be computed for other selected levels of fire load control. The over-all optimum level of fire control will be that at which the minimum-cost-plus-loss series is minimized as shown in Figure 8, indicating the maximum fire load that the presuppression organization may be economically developed to meet.

To this stage fire prevention has not been included in the model. Were it possible to identify both the costs and effects of prevention programs they could be included readily. The effects of fire prevention would alter the occurrence probabilities of numbers of concurrent fires per day of each fire intensity class (Figure 2). Occurrence probabilities of the range of fire loads would be changed, and the weighted damage + suppression cost curves of Figure 7 would require recalculation. It is doubtful if results of prevention programs would influence presuppression planning costs at the various fire loads.

In practice it may be impossible to isolate the effects of prevention campaigns on fire occurrence. Under such conditions prevention costs should be included with presuppression costs, since the unadjusted fire occurrence functions would reflect the unknown influences of prevention costs.

DATA REQUIREMENTS

Although this model may have some appeal on the basis of theoretical soundness, and in that it allows for use of experimental as well as historical data, it still may not provide the vehicle for practical determination of fire control standards at this time, since much of the information required by the model is undoubtedly

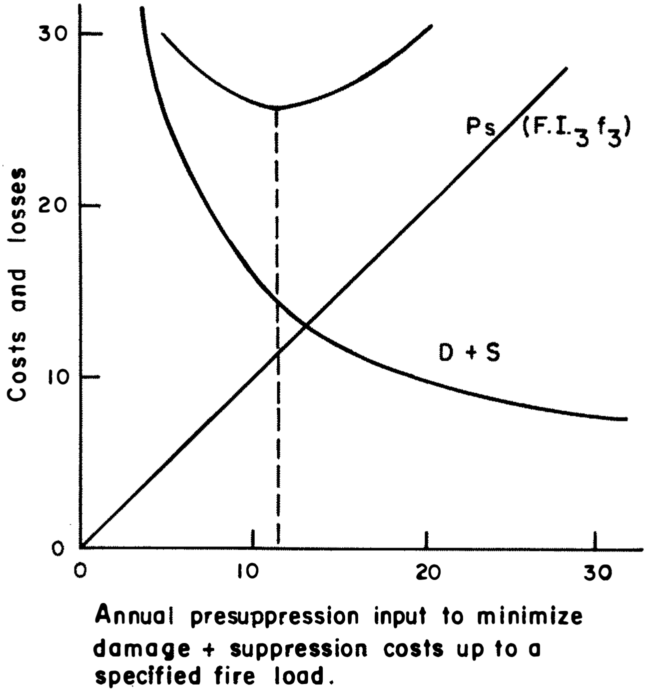

FIGURE 7. Least-cost-plus-loss determination for all probable fire loads with a fire control force designed to minimize damage + suppression costs up to a specified fire load.

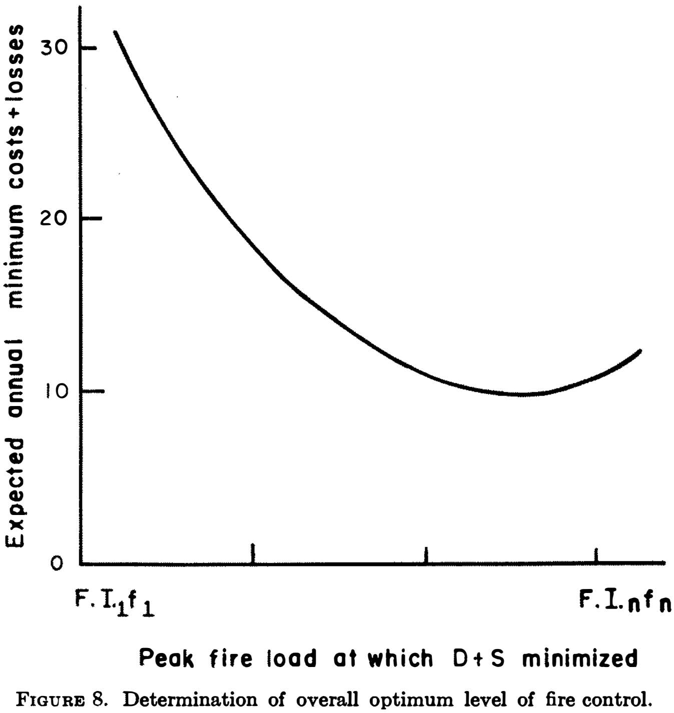

FIGURE 8. Determination of overall optimum level of fire control.

non-existent. At the same time, the model is based largely on fundamental relationships and, some of the difficulties associated with time-series data may be obviated. The model may be used for planning at various administrative levels. A calculated point of least-cost-plus-loss for a particular administrative or political unit may indicate possible losses greater than permissible from a policymaker's point of view. Should this be the case, the analysis will have proved useful in determining the fire load level above which some inter-agency mutual aid agreement might be worth considering. Furthermore, if a mutual aid agreement were in effect, advance knowledge of an administrative unit's fire control ability, as determined from the least-cost-plus-loss analysis, could prove invaluable. Knowledge of the unit's fire control ability together with forecasts of expected weather and possible fire load occurrence could permit decisions to call for emergency aid before rather than after a possibly disastrous fire load occurred.

The principal aim in synthesizing the model, to serve as something more than an academic exercise, was to point to some of the types of basic data and preliminary studies that seem prerequisite to useful estimations of fire control standards. This implies the development of detailed fire report forms for individual fires and their careful completion by knowledgeable personnel.

To learn of the influence of fire prevention techniques and costs, it seems essential to study each fire cause separately. A fundamental requirement is data on causative agents and ignition sources. Not only must the class of person causing fire be known but so must the agent of ignition used if the data are to be of real value for guiding prevention campaigns. A rather detailed classification of causes and agents was introduced in Canada about ten years ago in an effort to make fire cause data more useful and to ensure compatibility of data among the provinces. An example of the form used, as adapted by the Province of Quebec, is shown in Appendix I. Of course the development of cause classifications and forms is a rather simple matter compared to the detective work often required to determine actual fire causes.

In addition to the final costs and damages of a forest fire, a fire report should include statistics relating to the development of the fire and the control action taken so that the influence of presuppression organization and suppression action may be analyzed. A fire report should include information as to fire location, discovery means, elapsed time for the various phases of initial attack, the control time, and mop-up time. Information should be provided on the type and size of crews despatched to fires. Ideally reports should also provide a day-by-day account of weather, fuel types, slopes, aspects, areas burned, numbers of men, quantities of specific types of equipment employed, and the amount of fire line constructed and held by each. Fire fighting costs should be measured both in terms of hours of work and money. Fixed and variable costs should be recorded separately.

Each of the Canadian provinces has devised its own fire report form to provide most of the desired information. Since these forms were designed principally for accounting purposes most do not include day-by-day histories of fire behaviour and control action. The form used by the Province of Ontario (Appendix II) illustrates an up-to-date format, designed for rapid transferral of data to punch cards for machine computation. With the exception of provision for day-to-day fire history, the form does provide for most of the desired data.

The problem of estimating forest fire damages has been left to the end of this paper since the subject is complex and except for direct damage to timber values, has received little scientific attention in Canada. Again the task is first one of determining the physical consequences of fires of different intensities in different fuel types, topographies, seasons, climatic regions, and so forth. An understanding of the effects of fire on standing timber, site qualities, succeeding crops, re-establishment costs, and future presuppression organization is required. Post-fire investigations of these factors on all fires would be expensive, but studies of a number of fires exhibiting different combinations of the important variables could lead to development of useful forest fire damage appraisal tables as has been done successfully for several areas of the United States (Lindenmuth, *et al.* 1951) but not yet in Canada.

Even with the physical consequences of fire known, their impact in monetary terms remains difficult. Briefly the damage criterion for estimation of direct damage to timber or other forest attributes may be defined as the difference in property value occasioned by fire. In the most straightforward case of fire-killed mature timber, with no injuries other than to the existing stand, damage may be calculated as the stumpage value of the killed timber minus the value of material salvaged. Considering the rather poorly developed state of knowledge of fire consequences in Canada, this simple appraisal method is currently being recommended as a basic minimum standard procedure for use in Canada[1]. It assumes no direct damages except to the existing stands and it ignores possible indirect, or secondary, damages that might be suffered by firms or individuals whose livelihood is related to wood production.

The appraisal of damaged young growth is particularly difficult especially where, as in Canada, there is but a limited market for land bearing only young stands. Three standard options are available: replacement value; cost of production value; and expectation value. The first two do not seem appropriate for Canadian conditions where the eventual market price of mature timber may bear little relationship to the costs of producing it. Stands of volunteer timber would sell at the same prices as similar stands that had been planted. The expectation value seems most suitable, but it has a disadvantage in that it requires long-range price forecasting to estimate future values. Perhaps the most troublesome factor in all three approaches, however, is the selection of an appropriate rate of interest for discounting or compounding prices and costs. A small error in the interest rate is much more critical than the same degree of error in estimations of future market values because of the geometric nature of compound interest effects. Interest rate selection raises several important questions. Should the rate selected be a market rate, and if so should it relate to the private or public sectors of the economy; or should the rate be some sort of social rate of time preference, different from market rates? There is no unanimity on this critically important subject, and until there is, perhaps all the economist can do is use several rates in his analysis and leave it to the policy maker to decide which solution to accept for planning purposes.

Even more nebulous than damages to timber producing attributes of the forest are the effects of fire on recreational, watershed and other non-marketed forest attributes. The principle of appraisal remains the same, but the determination of the physical consequences of fire and the estimation of values for non-marketed goods and services are most difficult. Here is a field of research on which only the surface has been scratched. The least that can and should be done while awaiting development of evaluation techniques is to attempt to recognize and measure the physical effects of fire on these forest attributes. Just how and to

[1]Mactavish, J. S. Appraising fire damage to mature forest stands. Dept. Forestry, Canada. (In press.)

what extent do forest fires of different intensities and sizes influence wildlife populations, streamflow regimens and public use of forest areas? Long-range studies by experts in several disciplines are required.

CONCLUSIONS

The flood control planner has several advantages over the fire control planner. Floods are caused by weather elements, a mysterious enough subject to fathom; but, in addition to the weather, fire control is faced with the most enigmatic variable of all—man. The flood control planner has the basic engineering data at hand to advise him on the size, number and types of structures required to serve his purposes, but the fire control planner lacks most of these essential tools. Obviously, the first requirement is to gather accurate and complete data on the relationships of first the physical and then the economic inputs and outputs of fire control. The second step is to examine small facets of the over-all problem to determine how one variable acts on another in and among prevention, presuppression and suppression activities. Knowledge gained from such basic studies will make determination of optimum fire control plans feasible. In this modern age we are presented with highly sophisticated techniques for analyzing problems rapidly. For example, computer analysis with simulation techniques seems admirably suited to several facets of the fire control problem, but we are embarrassed by a dearth of basic data.

CONCLUSIONS

L'organisateur de la lutte contre les crues possède plusieurs atouts qui font défaut à l'organisateur de la lutte contre les feux de forêt. Les crues sont causées par un ensemble d'éléments météorologiques, dont le mystère est souvent impénétrable, alors que dans la lutte contre les feux de forêt un élément imprévisible entre tous, l'élément humain, vient s'ajouter aux éléments naturels. Celui qui est chargé d'organiser la lutte contre les crues a sous la main les données fondamentales du génie hydraulique qui lui enseignent le nombre, les dimensions et les genres de constructions qu'il lui faudra ériger, tandis que celui qui est chargé d'organiser la lutte aux feux de forêt manque de la plupart de ces données essentielles. Il saute aux yeux que ce qui importe d'abord c'est de rassembler les données précises et complètes sur le rapport entre les éléments matériels et économiques qui interviennent dans la comptabilité de cette lutte, tant à l'actif qu'au passif. Il s'agit ensuite d'étudier les aspects secondaires du problème dans son ensemble, afin de déterminer l'interaction des éléments variables qui interviennent dans les mesures de prévention, de pré-suppression et de suppression des incendies. Les données ainsi recueillies permettront alors d'élaborer un plan approprié et efficace de lutte contre les feux. De nos jours, nous disposons de techniques des plus perfectionnées pour l'analyse rapide des données. L'ordination par exemple, surtout lorsqu'elle se fait par la méthode analogique, semble convenir tout particulièrement à l'analyse des divers aspects du travail de lutte contre les feux de forêt; l'ennui, c'est que nous manquons de données fondamentales.

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Appendix I

TF-M-270

Formule PF-2A

PROVINCE DE QUÉBEC
MINISTÈRE DES TERRES ET FORÊTS
SERVICE DE LA PROTECTION

PROVINCE OF QUEBEC
DEPARTMENT OF LANDS AND FORESTS
PROTECTION SERVICE

CLASSIFICATION DES CAUSES D'INCENDIE
FIRE CAUSE CLASSIFICATION

Feu No / *Fire No.* .... Endroit / *Locality* ....

Nom de l'organisation de protection ou No du district du Service de la Protection / *Name of the protection organization or district No. of the Protection Service* ....

CAUSE DU FEU / SOURCE OF IGNITION		PERSONNE RESPONSABLE / INDIVIDUAL RESPONSIBLE																	
		Colon *Settler*	Cultivateur *Farmer*	Résident d'été *Summer resident*	Voyageur *Tourist*	Chasseur *Hunter*	Trappeur *Trapper*	Pêcheur *Fisherman*	Prospecteur *Prospector*	Mineur *Miner*	Ouvrier forestier *Forest worker*	Ouvrier de scierie *Sawmiller*	Cueilleur de fruits sauvages *Berry picker*	Employé de voirie *Road worker*	Cheminot *Railroader*	Militaire *Military*	Autre (Spécifier) *Other (Specify)*		Inconnu *Unknown*
Articles de fumeur *Smoking material*	Allumette *Match*																		
	Résidu de pipe *Pipe heel*																		
	Cigarette *Cigarette*																		
	Cigare *Cigar*																		
	Non-spécifié *Unspecified*																		
Feu de camp *Campfire*																			
Incendiaire *Incendiary*																			
Diverse connue *Miscellaneous known*	Etincelle de cheminée *Chimney spark*																		
	Explosifs *Explosives*																		
	Scie mécanique *Power saw*																		
	Autre (Spécifier) *Other (Specify)*																		
Inconnue *Unknown*																			
Feu d'abatis avec permis *Slash fire with permit*																			
Feu d'abatis sans permis *Slash fire without permit*																			
Défrichement *Land clearing*																			
Brûlage de déchets *Burning debris*																			
Brûlage d'emprise *Burning right of way*																			
Etincelle ou cendre d'une locomotive *Locomotive spark or ash*																			
Etincelle ou cendre d'une autre machine *Other engine spark or ash*																			
Foudre *Lightning*																			

Appendix II

Form F.P. 22
Revised 64-6078

Div.:
Fire No.:
Year:

ONTARIO
DEPARTMENT OF LANDS AND FORESTS
FOREST PROTECTION BRANCH

FIRE REPORT

Signature of person making report:
Title:
Date:

Approved by Chief Ranger:
Date:

Approved by District Office:

HEAD OFFICE

Entered in ledger
Checked by

Checked and coded by
Title

IDENTIFICATION

1. District
2. C.R. Division
3. Subdivision
4. Fire Number
5. Management Unit
6. Timber License
7. Date fire started—Known ☐ Estimated ☐
   (a) Year
   (b) Month
   (c) Day
8. Location where fire started—

Lot	Concession	Township or Base Map
Mileage	Subdivision	Railway

9. Land ownership
   Name of owner or licensee
10. Fire cause— Known ☐ Estimated ☐
11. General cause
12. Source of ignition
13. Responsible group
14. Evidence of fire cause
15. Size
   Class (A, B, C, D, E)

LEGAL

16. Infraction of Act? Yes ☐ No ☐
   Section:
17. Fire Protection Agreement? Yes ☐ No ☐
18. Did fire start on W.P. Area? Yes ☐ No ☐
19. Number of men on W.P. Area?
20. Responsibility disputed? Yes ☐ No ☐
21. Police investigation? Yes ☐ No ☐
22. Prosecution? Yes ☐ No ☐
23. Conviction? Yes ☐ No ☐

CONDITIONS

24. Fuel type where fire started:
25. Slope aspect

Code Column

DETECTION

26. Detection plan
27. Visibility

	Time	Agency
28. Disc. by (1)		
29. Disc. by (2)		

30. Reported by—to

CONTROL DATA

31. Initial action by
   Headquarters
   Group
   Means of attack
32. Distance travelled to fire by: Air
   Motor Vehicle Water
   Walking Total
   Travel time zone

33. Stage of control	Arrival	BH	UC
Date			
Hour			
Size of fire			
Number of men			
Number of foremen			

34. List of equipment and techniques used:

ELAPSED TIMES

35. Times recorded	Date	Time	Elapsed Times
(a) Start of fire			XXXX
(b) Discovered			XXXX
(c) Reported			(c - b)
(d) Get-away			(d - c)
(e) Arrival at fire			XXXX
(f) Travel	XXXX	XXXX	(e - d)
(g) Attack			(g - c)
(h) Control			(h - g)
(i) Patrol, Mop-up	XXXX	XXXX	(h - j)
(j) Fire Out			XXXX

36. Fire Boss: Name
   Regular Position:
   District:

Code Column

Appendix II (Continued)

FIRE WEATHER CONDITIONS

			Code Column												
37. Month															
38. Day															
39. Temperature															
40. Relative Humidity															
41. Wind Direction															
42. Wind Velocity															
43. Precipitation															
44. Drought Index															
45. Burning Index															

46. Name of weather station: Distance from fire:

FIRE FIGHTING COSTS

47. Value of equipment and supplies lost or burned (Attach list)

48. AIRCRAFT	Make and Registration	Rate	HOURS Servicing	HOURS Water Dropping	No. of Water Drops	COST Servicing	COST Water Dropping	Out-of-Pocket Costs
(a) L & F or Leased								X
								X
								X
								X
								X
								X
								X
								X
								X
	Total L & F							
(b) Commercial								X
								X
								X
								X
								X
								X
								X
	Total Commercial							

49. WAGES (a) E.F.F. Paid by Department	Pay Summary Serial No.	No. Men this Fire	Number of Hours Worked	Amount Charged to Fire	
					X
					X
					X
					X
					X
					X
					X
					X
					X
					X
					X
		Total L & F			
(b) Paid by others					X
					X
					X
					X
					X
		Total others			

(c) L & F Staff	From	To	Total Hours Worked	Rate Per Hour	Amount	
						X
						X
						X
						X
						X
						X
						X
						X
						X
						X
			Total L & F Staff			
					OUT-OF-POCKET SUB-TOTAL	

Appendix II (Continued)

Out-of-pocket Sub-total carried forward					
50. PROVISIONS					
Invoice Date	Supplier	Description	Total Amount of Invoice	Amount Charged to Fire	
					X
					X
					X
					X
					X
					X
					X
					X
					X
					X
					X
					X
		Value of Provisions issued from stock			X
		Total Provisions for fire			X
		Value of Provisions returned			X
		Amount charged to fire			

51. L & F EQUIPMENT—Operating Costs	L & F Numbers	Rate Per Hr. or Mi.	Hrs. or Miles Run	Amount	
Description of Unit					X
					X
					X
					X
					X
					X
					X
					X
					X
					X
					X
			Total Equipment Costs		

52. OTHER COSTS					
Invoice Date	Supplier	Description	Total Amount of Invoice	Amount Charged to Fire	
					X
					X
					X
					X
					X
					X
					X
					X
			Total Other Costs		

53. Unemployment Insurance Costs (Paid by Department)	
54. Workmen's Compensation (5¼% wages—Section 49a)	
55. Total Department out-of-pocket costs	
56. Total Cost Paid by others (attach summary)	
57. Total out-of-pocket costs	
58. Wages of L & F Staff (Section 49c)	
59. Overhead (10% of wages—(Section 49—a+b+c))	
60. Miscellaneous (Specify)	
GRAND TOTAL (Sections 57, 58, 59 & 60)	

61. Recommendation re Collection of Costs:

(a) ☐ Department to assume total cost.

(b) ☐ Head Office to invoice____________________

(c) ☐ Municipality of____________________to be invoiced for total out-of-pocket costs ☐ or

As per agreement ☐

Total out-of-pocket costs (Municipality and Department) $__________

50% of total out-of-pocket costs $__________

Less Total Municipality Costs $__________

Balance to be billed ☐ reimbursed ☐ to Municipality $__________

(d) ☐ District Office invoice sent to____________________in the amount of $__________Collected (date)__________Voucher No.__________

(e) ☐ Collected by Magistrate from____________________Amount__________

HEAD OFFICE USE ONLY

Final Department out-of-pocket costs

Municipality invoice in the amount of $__________passed for payment__________19____

Appendix II (Concluded)

FIRE DAMAGE

62.	Crown Land		Private	Totals
	Licensed	Unlicensed	Land	
(a) Acreage Burned by Ownership				
(b) Merchantable Volume Lost (cu. ft.)				
(c) Value of Merch. Volume				
(d) Total Immature Forest Values Lost				
(e) Total Value of Other Losses				
Total of all Losses (Section 62—c+d+e)				

63. General Type or Disturbance	Year	Area Burned	
		Crown	Private
Blowdown			
Insect Killed			
Logging Slash			
Burn not planted			
Planted area			
Conifer			
Deciduous			
Mixedwood			
Non-forested			
Totals			

List Non-Forest Losses (62e): ____________________

Is salvage recommended? Yes ☐ No ☐

Date...19..........

Signature..

Timber Management Forester

64. Remarks: ____________________

65. Map of Fire Area — Scale to 1 inch Complete section only for Fires 5 acres and over

(Show place where fire started. Attach separate map if fire area too great for space provided. Draw area burned to scale using legend at right as a guide. Show extent of private land concerned. Show survey lines (e.g. lot and concession lines) or name topographic features for ease in locating the fire.)

Scale of Map	Area per Square
10 ch. = 1″	6806 sq. ft.
20 ch. = 1″	.60 acres
40 ch. = 1″	2.50 acres
1 mile = 1″	10.00 acres
2 miles = 1″	40.00 acres
4 miles = 1″	160.00 acres