SIMULATING THE IMPACTS OF FIRE: A HYDROLOGIC COMPONENT

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Introduction

To estimate the impacts of fire on various components of southwestern ponderosa pine forest ecosystems, BURN, a computer simulation model which estimates benefits or losses after a fire occurrence, has been developed. BURN considers vegetative components, including mortality of forest overstories, regeneration of tree species, and production of herbaceous understories; wildlife components, including changes in population structures and effects on habitat qualities; and hydrologic components, including changes in annual streamflow and water quality parameters. The formulation, application, and future developmental work of the hydrologic component are described in this paper.

Formulation of Model

The general approach employed in the formulation of BURN was to assume that changes in an ecosystem after a fire can be viewed as flows of benefits or losses through time. Then, by contrasting the flows of benefits or losses against a control (an unburned area), so-called "time-trend response functions" can be developed (Lowe et al. 1978). These functions, which are graphical representations of benefits or losses that occur after a fire, form the basis for the formulation of BURN.

Time-Trend Response Functions

For each "ecosystem component" in BURN, a set of index values has been derived to characterize the resource. To present the source data in a consistent manner, the index values for post-fire conditions, derived by sampling for an attribute (1) at different points in time after a fire has occurred or (2) from sampling an attribute on a series of study areas representing different fire histories, are divided by index values obtained on a control area. The result is a unitless value, with the value of the control always 1.0. Assuming that the ecosystem component in question would respond in the same manner to fluctuations in weather conditions, time of year, and cyclic alterations, the ratios can be considered indicators of changes due to fire only.

Graphs are structured for each attribute investigated in the formulation of BURN, with the ratios plotted on the Y-axis and time after a fire on the X-axis. The control is represented by a horizontal line with a value of 1.0. Schematic curves represent the flows of benefits or losses for an arbitrarily selected time period of 20-years after the occurrence of a fire. If a curve is above the control line, it is assumed to measure a benefit, while a curve below the control line is a measure of a loss. If a ratio is not different from the control value, no change in benefit or loss is assumed. Again, these curves are the time-trend response functions, by definition.

Index of Benefits or Losses

The time-trend response functions are converted to an index of benefits or losses by initially determining streams of annual ratio values (Lowe et al. 1978). Then, the streams of annual ratios are converted to annuities, representing equal annual returns from a resource. While annuities normally are thought of in terms of dollars, the concept is applicable to non-monetary flows. The annuities are calculated from:

$$a = Vo \frac{i(1+i)^n}{(1+i)^n - 1}$$

where a = the annuity

Vo = the total of all annual values from a time-trend response function, discounted to time zero

i = the discount rate

n = the number of years in the analysis (1 to 20)

In the above calculation, Vo is determined from:

$$Vo = \sum_{n=1}^{20} \frac{Vn}{(1+i)^n}$$

where Vn = the value of the ratio taken from a time-trend response function for the individual years in the analysis (1 to 20)

The annuities allow a condensation of annual ratio values into a single annual index value. Theoretically, the annuity value of 1.0 is "indifferent" to the actual stream of annual ratios each year; since the ratio for the control is 1.0 for each year, the annuity also is 1.0. Annuity values that are higher or lower than 1.0 indicate benefits or losses, respectively.

Annuities calculated for 20-year periods are highly responsive to the discount rate selected. In essence, the discount rate determines how much "weight" is given to the different annual ratios. The greater the discount rate, the more heavily future yields are discounted. For example, if a 5 percent discount rate is selected, ratios for 1 year after a fire has occurred are weighed 2.5 times as heavily as ratios for 20 years after the fire. However, if a 10 percent discount rate is used, ratios for 1 year after a fire are weighted more than 6 times as heavily as ratios for 20 years after the fire.

Attributes Measured

In the hydrologic component of BURN, two attributes are considered currently, annual streamflow and water quality. Measurements of these attributes were obtained from secondary data sources, as described below.

Annual streamflow amounts were measured by water-stage recorders at control sections located at the outlets of study watersheds, near Flagstaff, Arizona (Campbell et al. 1977). These study watersheds had been burnd-over by a wildfire of different intensities. Unfortunately, due to the limited streamflow records available, extensions of annual streamflow response to the fire through a 20-year evaluation period were judgemental. However, the relative orders of magnitude for the annual ratio values employed in calculating the annuities are thought to be appropriate.

Water samples collected before and after a series of prescribed fires in the Santa Catalina Mountains, near Tucson, Arizona, were analyzed by the Department of Soils and Water at the University of Arizona (Sims et al. 1982). These baseline data sets provided the source information on water quality parameters. Specific chemical constituents analyzed included calcium, magnesium, sodium, chloride, sulfate, bicarbonate, fluoride, nitrate, pH, total soluble salts, and electrical conductivity. Supplementary information on water quality was obtained from Campbell et al. (1977).

Flowchart

The flow of activities followed in executing BURN to obtain estimates of benefits or losses after a fire has occurred is illustrated in figure 1. Through inputs of forest type, evaluation component, fire intensity, post-burning evaluation period, and a discount rate, an annuity value, termed a "fire impact index," is calculated. If desired, the simulation exercise can be recycled to analyze a series of discount rates, evaluation periods, fire intensities, and evaluation components.

A summary display is presented at the end of the simulation exercise, showing the estimates of benefits or losses, in terms of annuities, after the occurrence of a fire.

Application of Model

Perhaps, the best way to illustrate the application of the hydrologic component of BURN is through an example. In this example, we will examine the effects of a hypothetical fire on annual streamflow amounts from a watershed stocked with southwestern ponderosa pine forests.

Arbitrarily, a fire intensity of less than 5,000 Btu/second/foot has been selected to represent the intensity of the hypothetical fire. It is assumed that this fire has burned uniformly over the watershed. The length of the post-burning evaluation period will be 10 years. A discount rate of 5 percent

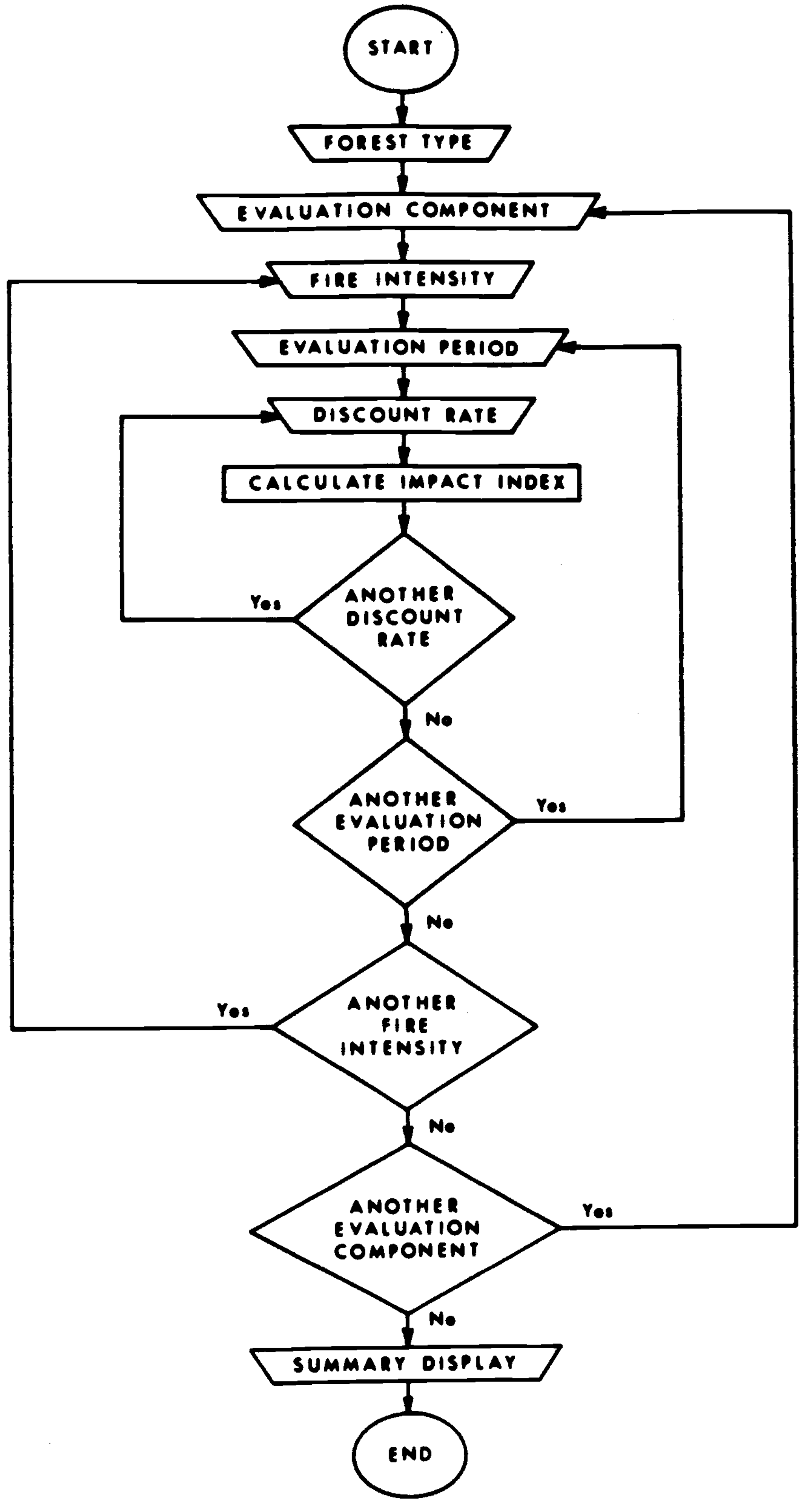

Figure 1. — Flowchart of BURN.

is used in this example. From this information, the fire impact index for annual streamflow is calculated to be 1.73.

As mentioned above, a fire impact index of greater than 1.0 represents a benefit. Therefore, one effect of the hypothetical fire is an increase in annual streamflow amounts. Specifically, the simulated fire impact index indicates that the amount of annual streamflow (measured before the fire occurred) will be increased 1.73 times (173 percent) through the 10-year evaluation, within the framework of the illustrated inputs.

If desired, the user can "re-cycle" the simulation exercise to investigate other combinations of post-burning evaluation periods and discount rates in studying the effects of the hypothetical fire on annual streamflow amounts.

Future Developments

BURN is considered to be a "prototypical" computer simulation model. Regarding the hydrologic component, all appropriate data sets available have been utilized in the initial structuring of the model and, to date, independent source data have not been collected to adequately evaluate the component of the model in terms of known conditions. It is anticipated that, once the required information becomes available, a "verification" of BURN will be undertaken.

Hydrologic attributes in addition to annual streamflow and water quality will be incorporated into the hydrologic component of BURN. Changes in the distribution of streamflow amounts, including time to peak and characteristics of recession flows, are examples of attributes that will be considered in future developmental work.

As currently formulated, only three arbitrarily-defined fire intensity options can be considered in BURN, namely: less than 5,000 Btu/second/foot, 5,000 to 10,000 Btu/second/foot, and over 10,000 Btu/second/foot. Also, a fire is assumed to burn uniformly over the entire area in question and does not account for partial burns. In the future, "refined" fire intensity options and options for non-uniform burning patterns should be offered to users for "more sensitive" analyses of the impacts of fire. Future work in the development of BURN must consider post-burning evaluation periods that are longer than 20 years. Sensivity analyses are needed to measure the effects of alternative discount rates on "fire index" values.

Once testing has been completed and the necessary modifications have been made to satisfy the appropriateness of BURN in southwestern ponderosa pine forest ecosystems, it is hoped that the basic structure of BURN, which is general in nature, can be extended to other forest and woodland types, in the southwestern United States.

References Cited

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