UPDATING HYDROLOGIC TIME-TREND RESPONSE FUNCTIONS OF FIRE IMPACTS

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Fire has historically been part of the natural environment of the southwestern United States. It is not surprising, therefore, that the frequent occurrence of wildfire and prescribed burning in the region has led to a useful body of knowledge and experience concerning the effects of fire on the resources of natural ecosystems. Nevertheless, the region's recent fire history has reinforced the need to learn still more about the effects of fire on ecosystem resources. Postfire changes in plant, animal, and soil and water resources take place at the time of, or shortly after, a fire occurrence (Whelan 1995; Bond and van Wilgen 1996; Pyne et al. 1996; DeBano et al. 1996, 1998). The magnitudes and durations of these changes can often be estimated when quantitative data are available. However, sufficient knowledge necessary to obtain reliable estimates for other than site-specific conditions is seldom available and, when this is the case, estimates of postfire changes in ecosystem resources must be made in the context of the data and information that are available or can be made available at reasonable cost. This paper outlines background issues and a plan to estimate postfire changes in ecosystem resources by updating the time-trend response functions of fire impacts.

Time-Trend Response Functions

Estimating postfire changes in ecosystem resources using time-trend response functions involves interpretations of the flows of damages to the resources and/or benefits for the resources through time since a fire occurrence, within a framework of both a physical and economic analysis of the postfire conditions (Lowe et al. 1978; Ffolliott et al. 1987; Ffolliott et al. 1988; DeBano et al. 1998). Some combination of on-site measurements and the experience and judgment of managers, fire behavior specialists, and ecologists often suffices for approximating the form of a time-trend response function for a resource and fire severity.

Time-trend response functions represent postfire changes of a resource in relation to the time since (a) a fire of a known severity or (b) a range of fire severities; that is, a set of time-trend response functions. A study being planned with scientists of the Rocky Mountain Research Station, USDA Forest Service, will focus on updating both forms of time-trend response functions with data and other information made available since their original formulations. The general framework for either developing or updating time-trend response functions is as follows:

- Resource values for postfire conditions are obtained by either (a) sampling the attribute at different points in time after a fire has occurred or (b) sampling the attribute on a series of burned areas representing fires of similar severity but varying fire histories. (Burned areas forming the data and informational base for the original formulation of the hydrologic time-trend response functions are included in the sampling.)
- The postfire values are then compared to corresponding resource values obtained by sampling unburned (control) areas. Assuming that the resource in question responds in the same manner to fluctuations in weather conditions, time of year, and cyclic alterations, differences in the two sets of values are considered to be indicators of changes in the ecosystem resources due to fire only.
- The differences in the two sets of values are shown as either (a) a stream of ratios over time between the resource values obtained for the burned and unburned areas or (b) absolute changes (either increases or decreases) in resource values over time following a fire in relation to the unburned area. Applying the ratio from function (a) to unburned values enables a manager to define a time-stream of postfire ecosystem resource values. This

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application provides a basis for calculating the sum of discounted fire-caused responses that are expected to occur over time (see below). The changes reflected in response function (b) permit the same kind of calculation for the resource to which it is applicable (DeBano et al. 1998). Time-trend response functions developed for different fire severities incorporate additional information, further sharpening the manager's ability to estimate fire impact over time.

Streams of annual ratios representing time-trend response functions can be converted to fixed-term annuities that represent equal annual returns from the resource of concern. Annuities are most commonly considered in monetary terms; however, the concept is equally applicable to non-monetary flows (Lowe et al. 1978; Ffolliott et al. 1988). Annuities allow the annual stream of ratios to be condensed into a single annual index value. Theoretically, an annuity value of 1.0 is "indifferent" to the stream of annual ratios (no change in postfire responses), an annuity value greater than 1.0 represents increases (positive postfire responses), and an annuity value lower than 1.0 indicates losses (negative postfire responses).

An Example: Estimating Postfire Changes in Streamflow

Figure 1 shows a time-trend response function illustrating a stream of ratios for changes in annual streamflow volumes in relation to time since a fire of a known severity in southwestern ponderosa pine forests. This function was developed by plotting ratios of the resource values obtained by sampling on burned and unburned areas (Ffolliott et al. 1987, 1988). Interpretation of this time-trend response function is illustrated through an example in which the effect of a fire is examined in terms of its effect on annual streamflow amounts. A moderate fire intensity (17,500 to 35,000 kilojoules/meter/second) with an average flame length of one-third to two-thirds of a meter is selected to characterize this hypothetical fire. It is also assumed (perhaps unrealistically) that the fire burned uniformly over the forest. The impact of the hypothetical fire on annual streamflow is examined for a postfire evaluation period of 10 years and (arbitrarily) at a 5 percent discount rate.

(A discount rate determines how much weight is given to the different annual ratios representing time-trend response functions. The greater the discount value, the more heavily future ratios are discounted. For example, if a 5 percent discount rate is used, ratios for 1 year after a fire are weighed 2.5 times as heavily as ratios for 20 years following a fire. If a 10 percent discount rate is used, however, ratios for 1 year after a fire are weighed more than six times as heavily as ratios for 20 years after the fire.)

Hydrologic changes that take place on a site after a fire has occurred can contribute to changes in annual streamflow amounts (Krammes 1990; Ffolliott et al. 1996; and others). Variables that affect both cumulative infiltration in time and infiltration capacity can be affected by fire to varying degrees, often adversely, resulting in decreased infiltration, increased overland flow, and (ultimately) increased streamflow amounts (Pyne et al. 1996; Brooks et al. 1997; DeBano et al. 1998). Additionally, considering rainfall events, the reduced forest density and litter cover following a fire and the possible occurrence of hydrophobic soils can decrease evapotranspiration losses, causing larger streamflow amounts. During winter months, however, a reduction in forest overstory caused by a fire can allow a greater proportion of a snowpack to be lost to evaporation processes, a phenomenon that results in less streamflow amounts. Nevertheless, annual streamflow amounts (considering both rainfall and snowmelt events) in southwestern ponderosa pine forests are generally increased by burning, at least in the first 20 years after the fire. The change in annual streamflow amounts (in terms of an annuity value) is 3.2 for the initial 10 years after the hypothetical fire; that is, annual streamflow amounts for the evaluation period will be 3.2 times that of the prefire annual streamflow amounts. This increase is attributed to the large increase in streamflow in the years immediately after burning.

Updating Hydrologic Time-Trend Response Functions

The plan for this collaborative study is to update time-trend response functions that were originally developed for annual streamflow volumes, suspended sediment concentrations, and nutrient, heavy metal, and other resources in southwestern ecosystems (Ffolliott et al. 1988). Burned areas with known fire histories and adjacent unburned areas, including areas forming the basis for development of the original time-trend response functions, will be evaluated or re-evaluated in terms of the attributes selected for updating and

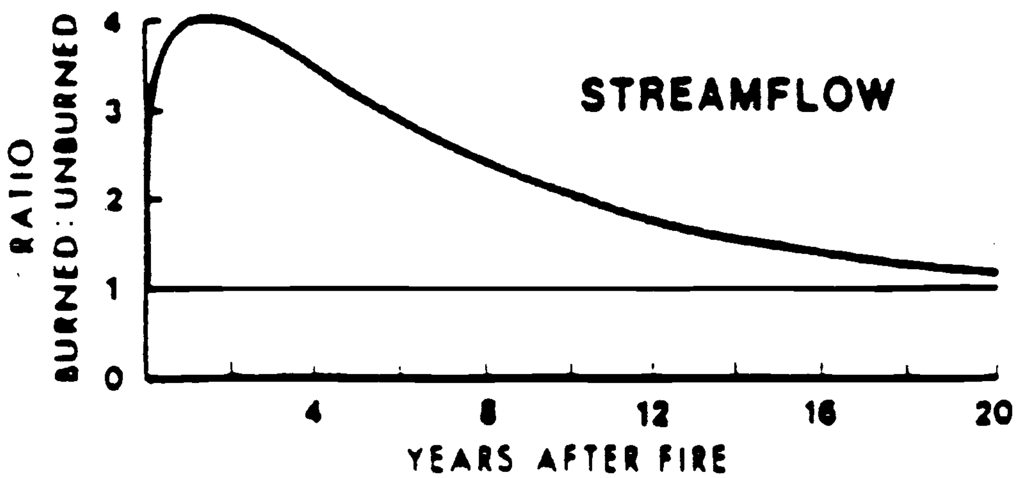

Figure 1. A time-trend response function shown as a stream of ratios for changes in annual streamflow amounts in relation to the occurrence of fire of a known severity in southwestern ponderosa pine forests.

expanding. The field measurements, observations, and monitoring necessary to determine postfire changes in the attributes and the analytical procedures required to formulate the updated time-trend response functions will be largely similar to those specified for earlier studies (Lowe et al. 1978; Ffolliott et al. 1987). Literature reviews of fire effects on hydrologic and other ecosystem resources will also help to structure time-trend response functions for the resources to be studied. The personal experiences and professional judgments of managers, fire behavior specialists, and hydrologists will be solicited in refining the forms of the time-trend response functions.

Initial emphasis will be placed on obtaining a better understanding of the factors that largely dictate the form or that could cause changes in the form of a time-trend response function. These factors include fire characteristics (such as intensity and severity), vegetation type, and soil characteristics. These and other factors considered individually, but more often in combination, affect the magnitude, rate of rise and recession, and length of time to attain levels representing prefire conditions for a hydrologic resource. The paired burned and unburned areas (watersheds) to be evaluated will be selected and evaluated in terms of these factors.

Revision of Computer Program

The updated time-trend response functions will be incorporated into the computer program BURN (Ffolliott et al. 1988) to expand the simulator's applications in terms of the ecosystem resources simulated, vegetative types considered, and fire intensities and severities confronted. The computer program will retain its original modular format for ease of future updating of the simulator, with a user-friendly interface for data entry. The revision of BURN, a user's manual, and examples of its application will be made available to interested people through publications, CD-ROMs, and the Internet.

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