SOME EFFECTS OF CONTROLLED BURNING ON SURFACE WATER QUALITY

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Introduction

Controlled burning is becoming an acceptable forest management practice to reduce excess fuels, decreasing the likelihood of destructive wildfires. In Arizona, controlled burns have produced other desirable effects, including thinning dense forest stands and increasing wildlife populations. However, the effects of this practice on water quality has not yet been fully ascertained.

Previous studies have indicated that higher intensity fires produce greater changes in water quality characteristics than do lower intersity fires. Higher intensity fires consume more litter and vegetation, reduce more soluble ions to ash, and expose more soil to erosion (Campbell et al. 1977, Zwolinski 1971, etc.). Therefore, it was hypothesized that relatively low intensity fires would have relatively little effect on water quality. This hypothesis was evaluated in the study reported upon herein.

Description of Study

The primary objective of the study was to describe the effects of low intensity controlled burning in an Arizona ponderosa pine forest on surface water quality and, if possible, to develop empirical equations to predict changes in water quality over time following a fire.

Study Area

Source data were obtained from a study area in the Santa Catalina Mountains, about 20 miles northeast of Tucson, Arizona. The study area, ranging in elevation from 8,000 to 8,300 feet, is located on slopes averaging 25 percent (10 to 45 percent). Soils are formed from underlying quartz monzonite parent material.

Ponderosa pine is the dominant forest cover. Limber pine and, to lesser extents, Douglas-fir, white fir, and silver leafed oak also grow on the area. No severe forest fires have been recorded on the study area since effective suppression was initiated, about 40 years ago. Preburn surface fuel was 24.7 tons per acre dry weight, with a mean depth of 2.2 inches and an average moisture content of 18.5 percent.

Field Procedures

Prior to a controlled burning in December of 1977, 18 randomly located surface runoff plots, 7-by-8 feet, were established. Nine of the plots were located on a northerly aspect and nine were on a southerly aspect. A covered gutter was installed to drain surface runoff into a plastic bag that was changed after each sample collection.

A total of 67 preburn and 119 postburn samples (0.11 gallon) were collected as soon as possible after runoff producing events. The preburn samples were collected during the months immediately prior to the controlled burning, and the postburn samples were obtained during the 10 months following. Total surface runoff volume was also measured when each plot was sampled.

To calculate fire intensity (FI), Byram's (1959) formula was solved for each of the 18 randomly located plots. This formula is:

$$FI = HWR$$

where: FI = fire intensity
H = heat yield
W = weight of available fuel
R = rate of spread

Inputs required to solve the above equation were estimated through evaluations of appropriate relationships and collections of on-site measurements, as described by Sims (1979).

Three additional variables quantified to characterize the controlled burning activity were:

1. Fire temperatures, measured at ground level and three feet above the ground with tempilaque pyrometers.
2. Density of the forest overstory, expressed in terms of basal area.
3. Percent of slope.

Laboratory Analysis

Water samples were analyzed by the Department of Soils, Water, and Engineering at the University of Arizona. Specific constituents assessed were: calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), chloride (Cl^{-}), sulfate ($SO_4^{=}$), bicarbonate (HCO_3^{-}), fluoride (F^{-}), nitrate (NO_3^{-}), pH, total soluble salts, and electrical conductivity. Sodium adsorption ratio (SAR) was also calculated.

Statistical Analysis

To expedite statistical analysis, an integrated system of computer programs, The Statistical Package for the Social Sciences (SPSS), was employed (Nie et al. 1975). All statistical tests were evaluated at the 0.05 level of significance.

Results and Discussion

Normally, controlled burns in the Santa Catalina Mountains are conducted in October and November, when fuel moisture contents and temperature ranges minimize the danger of losing control of the fire. However, in the year of this study, controlled burning was postponed until December because of an exceptionally wet autumn. At the time of the burn, air temperatures were in the mid-fifties and wind speed ranged from zero to three miles per hour.

Fire Intensity

The calculated fire intensity of the controlled burn in the Santa Catalina Mountains in December of 1977 ranged from 112 to 1,078 Btu's per foot per second, with a mean of 480 Btu's per foot per second. Therefore, even areas of highest fire intensity were still less than one-half of the fire intensity commonly associated with a moderate burn, and almost ten times less than the fire intensity of a severe burn (Campbell et al. 1977).

Although some overstocked areas of pulpwood-sized trees were destroyed, little sawtimber was lost. In general, the fire was confined to the forest floor.

Fire Temperatures

Unfortunately, soot deposits made it difficult to determine if the tempilaque paints had melted. However, 16 to 18 ground level pyrometers showed paints formulated to melt between 600 and 750°F were melted, and two showing ranges between 900 and 1050°F also melted. Indicator stripes between 150 and 300°F had melted on 10 of 18 pyrometers three feet (1 meter) above the ground surface. Seven stripes indicated temperatures between 300 and 600°F melted, and one showing ranges between 750 and 900°F melted.

Water Quality

No consistent differences were found in mean concentrations of the chemical consituents in either preburn or postburn water quality samples collected from runoff plots located on the different aspects. Therefore, the source data were pooled for subsequent analysis.

Of the chemical consituents assessed, mean concentrations of calcium, magnesium and flouride, and the average pH increased after the controlled burning, while the sodium adsorption ratio (SAR) decreased. Differences in mean concentrations of the other consituents were not significant.

Increases in calcium and magnesium can be considered beneficial in water being used to irrigate agricultural crops. An increase in flouride can increase the general quality of drinking water (McKee and Wolf 1963). Although pH increased (from approximately 6.2 to 6.4), both preburn and postburn values are especially suitable for irrigation of southwestern soils.

In general, higher sodium adsorption ratios (SAR's) indicate that increased amounts of sodium, rather than of calcium and magnesium, will be adsorped in soil cation exchanges, leading to a breakdown of soil aggregates and causing soils to become less permeable (Donahue et al. 1977). In this regard, a decrease in the sodium adsorption ratio (SAR) as reported herein, may be quite desirable.

Preburn water samples, expressed in terms of mean concentrations, showed quality levels were within drinking water standards established by the Environmental Protection Agency, the U.S. Public Health Service, and the World Health Organization for magnesium, sulfate, flouride, and nitrate. Following controlled burning, mean concentrations of these constituents were still within drinking water standards, even though the concentrations of magnesium and flouride increased. None of the other chemical constituents analyzed have been included in published drinking water standards.

Change in Water Quality Over Time

To evaluate changes, if any, in water quality over time since the controlled burning, regression analysis techniques were used to define empirical equations. Of the chemical constituents assessed, concentrations of only three, sodium, pH, and the sodium adsorption ratio (SAR), changed over time following the burn. Empirical equations defining these changes are:

$$Na = 11.0 - 0.0023(FI) - 0.0044(BA) - 0.014(DB) + 14.8(PP) - 0.67(RO) \quad (1)$$

$$r^2 = 0.61$$

$$pH = 6.60 - 0.0014(FI) + 0.00014(MT) - 0.00037(BA) - 0.55(SL) - 0.0090(DB) + 4.2(PP) - 0.0085(RO) \quad (2)$$

$$r^2 = 0.70$$

$$SAR = 0.76 - 0.00011(FI) - 0.000026(MT) - 0.00036(BA) - 0.0023(DB) + 0.98(PP) - 0.054(RO) \quad (3)$$

$$r^2 = 0.68$$

where: NA = sodium, in milligrams per liter

pH = hydrogen ion, in pH units

SAR = sodium adsorption ratio

FI = fire intensity, in joules sec^{-1} $meter^{-2}$

MT = maximum fire temperature, in degrees F

BA = density of forest overstory, in basal area per acre

SL = slope, in percent

DB = number of days since burn

PP = precipitation, in millimeters per storm event

RO = surface runoff, in liters per five-square-meters per storm event

It must be emphasized that the above-defined empirical equations have not been independently verified and, therefore, may only be applicable to those conditions encountered in the study.

Conclusions

With respect to describing the effects of low intensity controlled burning in an Arizona ponderosa pine forest and to developing empirical equations to predict changes in water quality over time following a fire, the following conclusions can be reached as a result of the study reported upon herein:

1. Mean concentrations of calcium, magnesium, and flouride, and the average pH increased following the controlled burning. The sodium adsorption ratio decreased. No other statistically significant differences were noted.
2. Empirical equations were developed to predict changes in sodium, pH, and the sodium adsorption ratio over time.

References Cited

Byram, George M. 1959. Combustion of forest fuels, and forest fire behavior. In Forest Fire: Control and Use. Kenneth David, Ed., McGraw-Hill Book Co., New York, 686 p.

Campbell, R. E., M. B. Baker, Jr., P. F. Ffolliott, F. R. Larson, and C. C. Avery. 1977. Wildlife effects on a ponderosa pine ecosystem: An Arizona case study. USDA Forest Service, Research Paper RM-191, 12 p.

Donahue, Roy L., Raymond W. Miller, and John C. Skickluna. 1977. Soils: An Introduction to Soils and Plant Growth. Prentice-Hall, Inc., New Jersey, 626 p.

McKee, Jack Edward, and Harold W. Wolf. 1963. Water quality criteria. The Resources Agency of California, State Water Resources Control Board, Publication No. 3-A, 548 p.

Nie, Norman H., C. Hadlai Hull, Jean G. Jenkins, Karin Steinbrenner, and Dale H. Bent. 1975. Statistical Package for the Social Sciences. McGraw-Hill Book Co., New York, 281 p.

Sims, Bruce D. 1979. Effect of fire on water quality in an Arizona ponderosa pine forest. Master's Thesis, University of Arizona, 60 p.

Zwolinski, Malchom J. 1971. Effects of fire on water infiltration rates in a ponderosa pine stand. Hydrology and Water Resources in Arizona and the Southwest 1:107-112.