INFLUENCE OF CLEARING PONDEROSA PINE ON TIMING OF SNOWMELT RUNOFF

By

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INTRODUCTION

In forests which receive a major portion of their water yield from melting snow, timber harvesting generally increases water yield from a watershed (Hibbert 1967) by reducing evapotranspiration losses, increasing source-area concentration of snowmelt water, and increasing year-to-year carryover of soil water (Gary 1979). Removal of forest overstory by clearcutting in patches, strips, or blocks increases snow accumulation in these areas and increases the amount of water available for streamflow (Gary 1975, Leaf 1975).

Timber harvesting often increases the amount of snow retained until later in the spring when more of the snowpack is converted to streamflow because of more rapid melt rates (Satterlund and Eschner 1965). Tests in Arizona resulted in accelerated spring snowmelt from strip-cuts on east and west aspects while little change was produced on strips with south and southwest aspects (Hansen and Ffolliott 1968). Rothacher (1965) found that strips oriented east-west retained snow longer than in the undisturbed forest.

This paper analyzes the predominate snowmelt runoff regimes on two ponderosa pine forested watersheds in north-central Arizona and describes how clearing the forest overstory affects the timing of concentrated winter-spring runoff.

STUDY AREA

The two adjacent watersheds used in this study are 80 km south of Flagstaff, Ariz., in the ponderosa pine type of the Beaver Creek drainage. The treated watershed is 184 ha. An adjacent watershed established as a control is 369 ha.

Soils on both watersheds are developed from volcanic basalt and cinder parent materials. The soil derived from basalt is Brolliar, a fine, montmorillonitic, Typic Argiustoll; the soils derived from the cinder parent material are Sponseller, a fine loamy, Argic Cryoboroll and Siesta, a fine montmorillonitic, Typic Rhodustalf. These soils are generally silty clays or silty clay loams less than 1 m deep (Williams and Anderson 1967).

Before the watershed was treated, both study basins were stocked with uneven-aged stands of ponderosa pine (*Pinus ponderosa* Laws.) interspersed with Gambel oak (*Quercus gambelii* Nutt.) and alligator juniper (*Juniperus deppeana* Stend.). Overstory basal area before treatment was 24 and 28 m^2/ha on the treated and control watersheds, respectively. Canopy density, leaf area index, and average site index (height in meters at 100 years) on the treated watershed were 80 percent, 5.2, and 17 m, respectively.

Temperature and precipitation regimes on these two watersheds are similar to those previously reported for southwestern ponderosa pine (Schubert 1974, Brown et al. 1974). Mean annual temperature in the pine type on Beaver Creek averages 7.2° C, and average monthly temperature varies from -2.2° C in January to 17.8° C in July. Mean annual precipitation on the treated watershed (1960-1977) is 583 mm. The highest annual precipitation, 912 mm, was during the 1973 water year (October 1 through September 30), followed by a low of 364 mm in 1974.

Two major precipitation seasons characterize this area. The winter season from October through April has the highest water yield. Winter precipitation averages 366 mm, 63 percent of the annual total. Most of the remaining precipitation falls during July, August, and September.

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Winter precipitation is associated with widespread, protracted, frontal storms. Snowfall commonly begins in November and increases into December, then usually declines in January and February, followed by an increase to a peak in March. Average peak water equivalent of the snowpack is 102 mm.

Nearly all summer precipitation falls during thunderstorms; and, although they are frequent, individual storms usually cover relatively small areas. Mean summer rainfall averages 217 mm.

Continuous streamflow records on each watershed are obtained from a precalibrated, concrete, trapezoidal flume (Brown et al. 1974). Annual streamflow on the treated watershed has varied from 12 mm in 1974 and 1977 to 701 mm during 1973. Mean annual streamflow from the treatment watershed before the overstory was completely cleared (1960-1966) was 150 mm and 93 mm on its control watershed.

Most of the water yield produced on the Beaver Creek experimental watershed is in the winter. During the period of this study on the treatment watershed, in 14 of the 18 years, 90 percent or more of the annual discharge occurred during the winter season. The soil mantle is recharged during the winter when water from rain or snowmelt is available and evapotranspiration demands are low. Most streamflow is in March and April, terminating in early May. Most stream channels in these headwater basins become dry before the onset of summer rains.

TREATMENT AND ANALYSIS

All merchantable commercial poles and sawtimber were removed and the remaining nonmerchantable timber were felled in 1966-1967 on the treated watershed, residual slash was windrowed. Tree species (predominately oak and some juniper) were allowed to sprout and grow following the initial clearing.

Runoff regimes can be analyzed without disturbing the time sequence of flow by using the half-flow date and duration concept developed by Court (1961). This method lends itself to study of runoff regimes that have snowmelt as a major component of streamflow. The half-flow date, as defined by Court, is the date on which streamflow, accumulated since the beginning of the water year, reaches a total of one-half the annual flow (figure 1). The half-flow interval is the length of time between the one-quarter and three-quarter flow dates, determined in the same manner as the half-flow date (figure 1).

However, these variables do not satisfactorily describe the winter-spring runoff conditions in the mountainous, semi-arid region of Arizona. In this area, heavy streamflow may occur almost any time within the period of snow accumulation. Consequently, half-flow dates and intervals vary greatly.

To reduce variation in half-flow dates and intervals, a modified Court's procedure is used in this analyses. Instead of basing intervals and dates on annual flow, winter flow amounts are used (flow for period October 1 through April 30). Also, the shortest half-flow interval is used (Satterlund and Eschner 1965). To find the shortest interval requires accumulating daily flow for successive periods, after October 1, through late spring and selecting the shortest interval including one-half the winter runoff (figure 1). Use of this interval ensures that the most concentrated period of runoff is selected regardless of when it occurs. The half-flow date is redefined as the date on which the midpoint in flow of the shortest half-flow interval occurs (figure 1).

In areas such as Arizona, major runoff periods often occur in a short period of time, often 1 to 2 weeks in length. Therefore, the use of a shorter interval may be more useful. In analyzing the synchronization of flow over a shorter period, high flows may be more sensitive and of greater concern in revealing time differences between watersheds (Satterlund and Eschner 1965). Consequently, the shortest quarter, two-tenths and one-tenth flow interval is also used in this analysis. These shorter intervals are calculated in the same manner as the shortest half-flow intervals.

Because of inconsistent posttreatment behavior between control and treated watersheds, the usual paired watershed covariance analysis was not informative. Instead, a regression analysis was used to develop a relationship between the shortest flow dates and intervals on the treated watershed and its control. Ninty-five percent confidence limits were then placed around these regressions, and the individual posttreatment years were

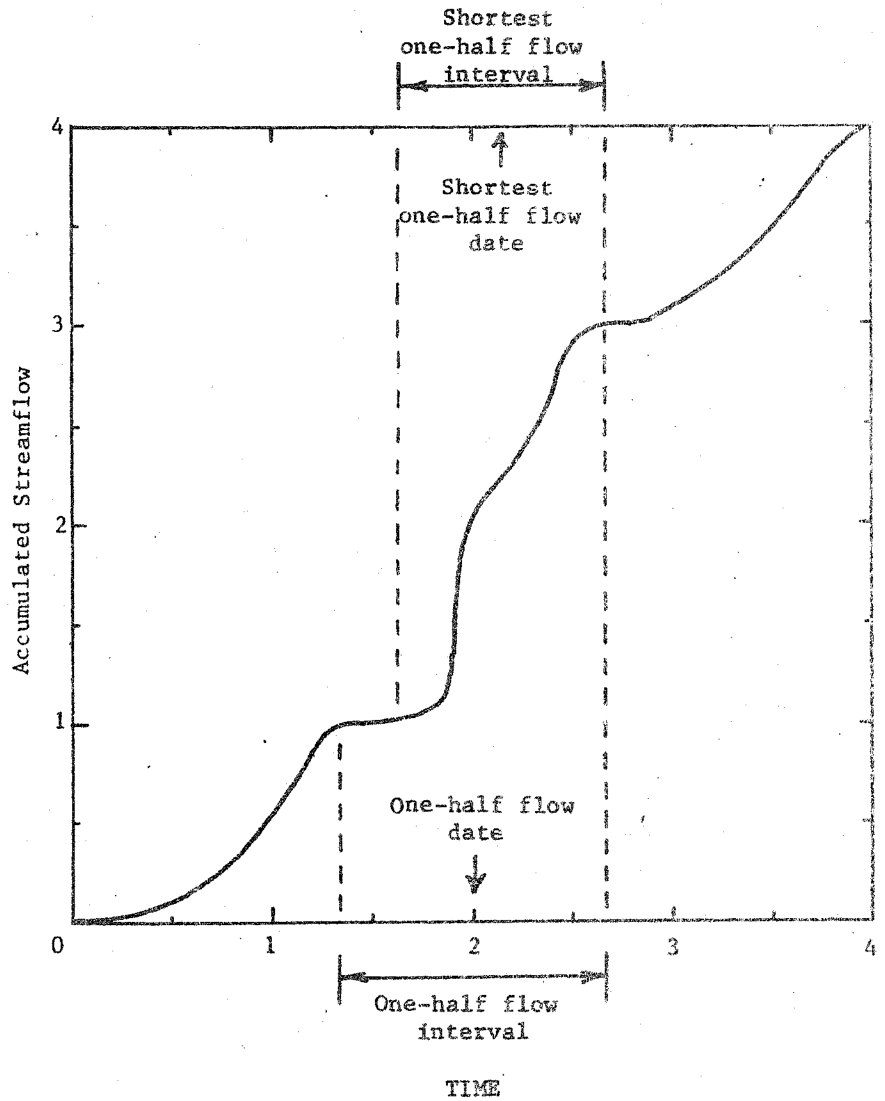

Figure 1.--Relationship of the original one-half flow interval and date concept to the modification used in this study.

tested to see if they fell within this confidence range. Those years which fell outside of the confidence range were assumed to have been affected by the clearing treatment.

Streamflow for 19 years of the study has been divided into two periods. The seven years from 1960 through 1966 are the pretreatment or calibration years, and the last 10 years from 1968 through 1977 are the treatment period following the clearing of all overstory vegetation. The year of treatment (1967) is not considered in the analysis.

RESULTS

The shortest one-tenth and two-tenths flow variables are the most sensitive to the study conditions (figures 2 and 3). Analysis of the shortest one-tenth flow dates shows that five of the posttreatment years fall below the 95% confidence limit (figure 2). Similar analysis of the two-tenths flow dates shows that four of the posttreatment years fall below the 95% confidence limit (figure 2).

Inspection of the streamflow data indicate that two processes are responsible for initiation of the concentrated flow periods. One is precipitation and the other is an increase in snowmelt as initiated by increase in air temperature. Years with snowmelt-caused increases in March or April generally fell within the 95% confidence limit, indicating lack of a treatment response. Snowmelt-caused increases earlier in the year generally

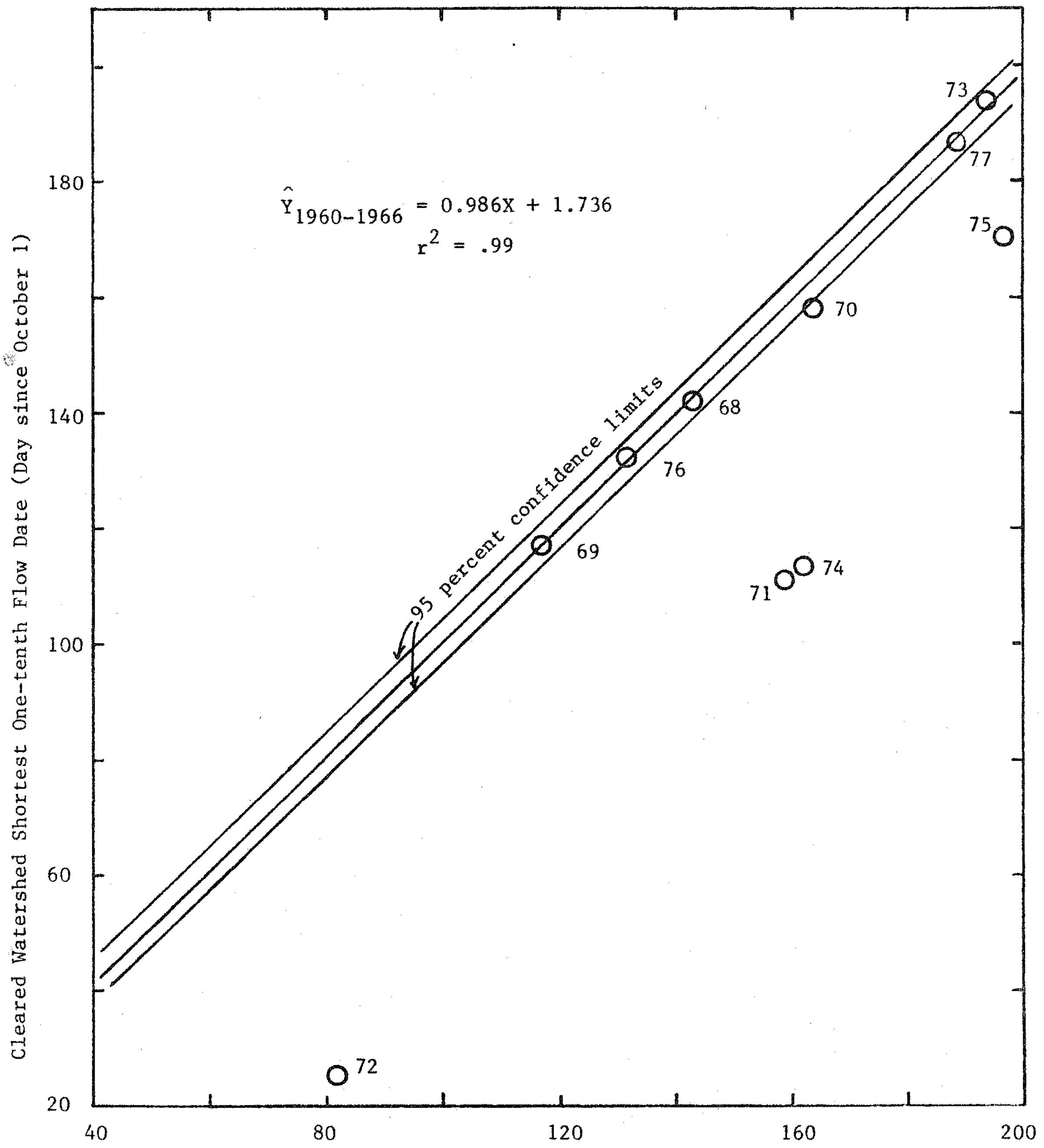

Figure 2.--Relationship of the posttreatment one-tenth flow dates to the pretreatment regression.

fell below the confidence limit. Years with flow increases caused by 50 or more mm of precipitation during the previous 5 days, generally fell within the confidence limit; those with less than 50 mm of precipitation generally fell outside the confidence limit.

The mean advance in the shortest one-tenth flow date outliers was 37 days, with a standard deviation (S) of 21 days; the mean for the shortest two-tenths flow date outliers was 57 days, with an S of 11 days.

Analyses of the shortest flow intervals were not conclusive. The one- and two-tenths flow intervals are so short (about 1 1/2 to 2 1/2 days) that no significance can be shown when working with daily flow as the smallest unit of measure.

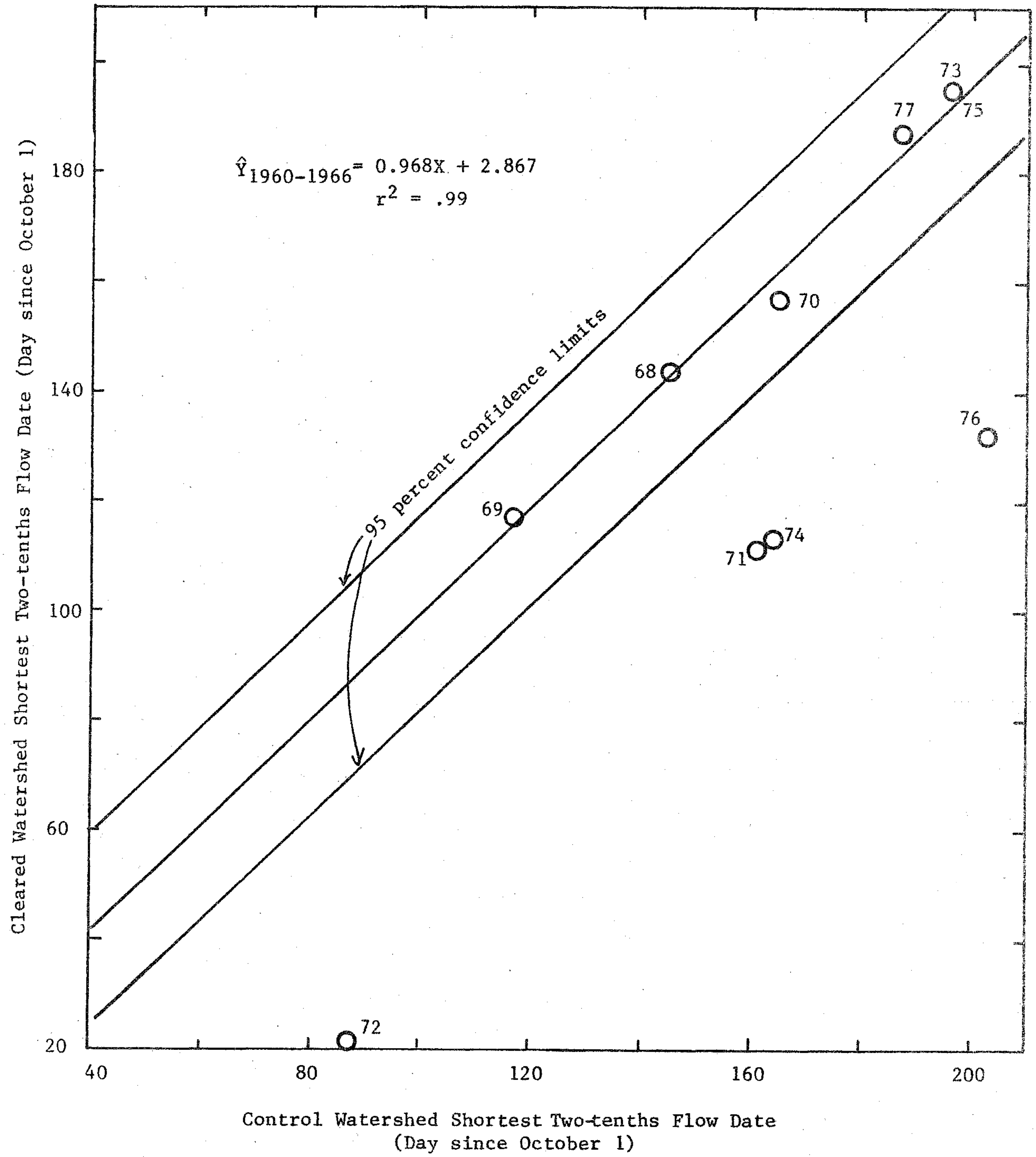

Figure 3.--Relationship of the posttreatment two-tenths flow dates to the pretreatment regression.

The use of the shortest half- and quarter-flow dates and interval are not sensitive enough to satisfactorily describe the winter-spring snowmelt conditions on the study areas. Half-flow dates ranged from February to early April for the pretreatment period and from mid-January to mid-April for the posttreatment period, on the two study basins. Half-flow intervals ranged from 2 to 38 days before treatment and from 1 to 50 days after the clearing treatment.

DISCUSSION AND CONCLUSIONS

The use of flow interval and date analyses, show promise as a technique for analyzing streamflow regimes in the Southwest. However, because the half-flow variables as defined by Court (1961) do not satisfactorily describe conditions in Arizona, modification of Court's procedure is necessary. These new variables ensure that the most concentrated periods of runoff are included.

Because of the characteristic short, concentrated, winter-spring runoff conditions in the Southwest, the one-tenth and two-tenths flow variables provide the most useful results. These flow variables indicate that there may be a significant advance in the shortest flow date after clearing.

There are indications that timing of high temperatures or amounts of rainfall modifies the forest influence on snowmelt runoff. When snowmelt-caused flow events come early, concentrated flow from cleared areas will probably be advanced. When precipitation-caused flow events have less than 50 mm of new rainfall, concentrated flow from cleared areas will also be advanced. These conditions were experienced 40% to 50% of the time during the posttreatment period. However, if snowmelt-caused flow events come later in the season or precipitation-caused flow events are greater than 50 mm effects of harvesting will generally be lost.

The change in flow dates is the result of a combination of reduced evapotranspiration on the cleared watershed, and possible changes in snowmelt timing and snowmelt rates. With reduced evapotranspiration losses, less precipitation or early winter snowmelt is required to recharge the soil deficit on the treated watershed. This condition provides the opportunity for the concentrated runoff to occur earlier in the season. Clearing the forest overstory apparently makes the watershed more responsive to precipitation and snowmelt events.

Although the concentrated one- and two-tenths flow periods only include 12 or 25 mm of the mean winter streamflow from the untreated ponderosa pine watersheds, they usually include the first or second highest peak discharges of the season. This makes these flow periods important hydrologically and of practical significance to the land manager.

Clearing a ponderosa pine basin appears to advance concentrated winter runoff 40 to 50% of the time. These results suggest the possibility of forest managers influencing flow timing by vegetation manipulation. By developing a combination of open (or possibly thinned) forested areas with more densely stocked areas, flow regime may be extended over a longer runoff period, thereby, reducing maximum flow from a given management area.

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