Snowpack Hydrology in the Southwestern United States: Contributions to Watershed Management

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Abstract.—Less than 10% of the annual precipitation in the Southwestern United States is recovered for use by people; most of the precipitation is lost by evapotranspiration. A large portion of the precipitation that is recovered originates on watersheds in montane forests. Even here, 80% to 90% of the precipitation is currently unavailable to downstream users. The possibility of increasing the amount of recoverable precipitation in this region is greater for snow than rain. A 50-year review of snow hydrology in the Southwestern United States is presented to indicate the possibilities for increasing snowmelt-water yields within integrated watershed management.

Introduction

Less than 10% of the annual precipitation in the Southwestern United States is recovered for use by people; most of the precipitation is lost by evapotranspiration. A large portion of the precipitation that is recovered originates on forested watersheds in mountainous areas, where currently 80% to 90% is unavailable for downstream users. The possibility of increasing the amount of recoverable precipitation from forested watersheds is greater for snow than for rain (Ffolliott et al. 1989, Ffolliott 1993). Snow accumulates throughout the winter, providing a reservoir of water potentially available for downstream use in the spring. If snowmelt-water yields were increased significantly, additional water would be available to refill reservoirs or recharge groundwater aquifers.

Snowpack Conditions

Snowpack conditions in the Southwestern United States are often either excessively high or low in comparison to other regions of the country. Fluctuations in winter precipitation patterns result in a few wet years interspersed with several average and below average years (Diaz 1983). These fluctuations greatly affect the intermittent snowpack buildups on high-elevation forested watersheds. Intermittent snowpacks, which often disappear between successive storms, vary greatly in their contributions to annual water yields and to the flow of water to downstream users.

Forest Management Practices

Forest management practices to increase recoverable water yields from snow include forest thinning and forest overstory clearing (Ffolliott et al. 1989). Various intensities of forest thinning and arrangements, sizes, and patterns of clearing are possible.

Forest Thinning

Inventory-prediction relationships describing snowpack conditions within the region's montane forests of the region indicate that snowpack-water equivalents generally increase as forest densities decrease. With inventory-prediction relationships, watershed managers can prescribe thinning practices to increase snowpack-water equivalents on-site, which will then convert into recoverable water.

Storage-duration values, obtained by adding snowpack-water equivalent measurements from successive sampling dates (Wilm 1948), provide information on the temporal variabilities of snowpack conditions. Maximum-index values indicate high initial storage and slow melt, while minimum-index values indicated low initial storage and rapid melt. Studies have shown that maximum storage-duration values are associated with low forest densities, cool sites, and high elevations, while low storage-duration values are associated with high forest densities, warm sites, and low elevations.

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Clearing

Greater accumulations of snow for possible conversion into recoverable water are available in cleared openings than under forest canopies. The greatest accumulations of snow are in cleared strips and patches with less than 1-1/2H (H = height of adjacent trees) in size. While clearing forest overstories affects snowfall accumulation patterns, the amount of snowfall onto the watershed remains unchanged.

A series of three-dimensional, time-space models that describe snowpack conditions in and adjacent to openings can be used to formulate forest management practices that maximize or minimize the effects of patch cutting on snowpack conditions (Ffolliott 1983). Information from these models is helpful to watershed managers when increased water yields from snowpacks are possible.

Process and Theoretical Studies

Results from process and theoretical studies allow watershed managers to better understand the causal nature of relationships between snowpack conditions and forest overstories. Deposition of intercepted snow in tree canopies has been evaluated with time-lapse imagery to determine the relative significance of snowfall interception in the water budget (Tennyson et al. 1974). Most of the intercepted snow eventually reaches the ground by snowslide, wind erosion, or canopy melt; thus, it does not necessarily represent a significant loss of the water budget.

Loss of snow from a landscape is due to melting of the snowpack or to a combination of melting, evaporation, and sublimation. Factors influencing evaporation and sublimation include site (aspect, slope, etc.), latitude, distance from the ocean, and elevation (Avery et al. 1992). Sublimation rates are higher for more northerly sites, increasingly inland sites, and higher elevations. Studies in the Southwestern United States indicate that snow cover losses, as little as 25% and as much as 70%, are due to melting alone or to a combination of melting, evaporation, and sublimation.

Theoretical studies have centered on synthesis of models to describe short- and long-wave solar radiation exchanges between snowpacks and forest canopies (Bohren and Thorud 1973, Bohren and Barkstrom 1974). These short-wave and long-wave radiation exchanges vary with tree canopy structures. Furthermore, the effects of manipulating forest overstories on short-wave and long-wave solar radiation transfer and the accumulation and subsequent ablation of snowpacks are predictable.

Runoff Efficiencies

One measure of the effects of physiographical and climatological factors on the quantity of snowmelt runoff from a watershed is runoff efficiency, which is the portion of a snowpack's water equivalent that is converted into surface runoff (Solomon at al. 1975). Both fixed and variable factors influence runoff-efficiency values. Fixed factors include slope percent, aspect, soil type and depth, and watershed configuration. Variable factors are year-to-year differences in the rates of snowmelt on the watershed and preceding moisture conditions.

Equations that predict runoff efficiency from variables measured before peak seasonal snowpack accumulation and during the snowmelt-runoff regime are available (Solomon et al. 1975). Watersheds with the greatest peak seasonal snowpack accumulations and at the highest elevations have the most efficient snowmelt-water yields. Consequently, forest management activities implemented to increase snowpack-water equivalents at peak seasonal accumulation have the greatest potential for snowmelt-water yield improvement.

Simulation Models

Snowpack conditions at a point-in-time reflect the combined effects of accumulation, redistribution, and melt processes that occurred before that point-in-time. Simulation models are available to separate the complexities of these processes and to allow for prescription of forest management activities to manipulate snowpack conditions. These simulators are useful in quantifying on-site snowpack accumulation, redistribution, and melt processes within a dynamic framework (Ffolliott and Rasmussen 1979). It is also necessary to know the contributions of the melting snowpacks to streamflow regimes from these high elevation watersheds.

Modification of a snowmelt simulation model for Colorado subalpine forests provides predictions of the contributions of the relatively shallow and intermittent snowpacks in the Southwestern United States to streamflow. This generalized model requires limited knowledge of watershed and snowpack parameters to initialize (Solomon et al. 1976). The driving variables are daily values of maximum and minimum air temperatures, precipitation amounts, and impinging solar radiation loads. Verification of the simulation model on watersheds representing a range of conditions common to high elevation, forested watersheds in the region has been satisfactory. Interrogations of the model provide information on watershed conditions most favorable to increased snowmelt-water yields.

Management Implications

Implementation of forest management practices has increased annual water yields from watersheds in the mountains of the Southwestern United States from 5% to 100% (Ffolliott et al. 1989, Ffolliott 1993). Larger increases occur in wet years, when the soil mantle was recharged before snowmelt began. Little or no increase in snowmelt-water yields occur in very dry years, when most of the snowmelt recharges the soil mantle.

There is debate on what proportion of streamflow increases attributed to forest management practices actually contributes to downstream water supplies. Brown and Fogel (1987) suggested that the proportion is relatively small because of transmission losses, evaporation, seepage, and reservoir spills. Simulation of water routing with and without implementation of forest management practices by these authors indicated that less than half of the streamflow increase is likely to reach consumptive users downstream.

Summary

Empirical field observations, process and theoretical studies, and simulation investigations provide a basis for the formulation of management guidelines to enhance snowmelt-water yields on high-elevation forested watersheds in the Southwestern United States. Forest management practices can be designed to increase the amount of recoverable water from melting snowpacks on watersheds with high-runoff efficiencies. These management practices can also furnish livestock and wildlife forage, wildlife habitats, wood, and amenity values in combinations needed by people in the region into the coming century.

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