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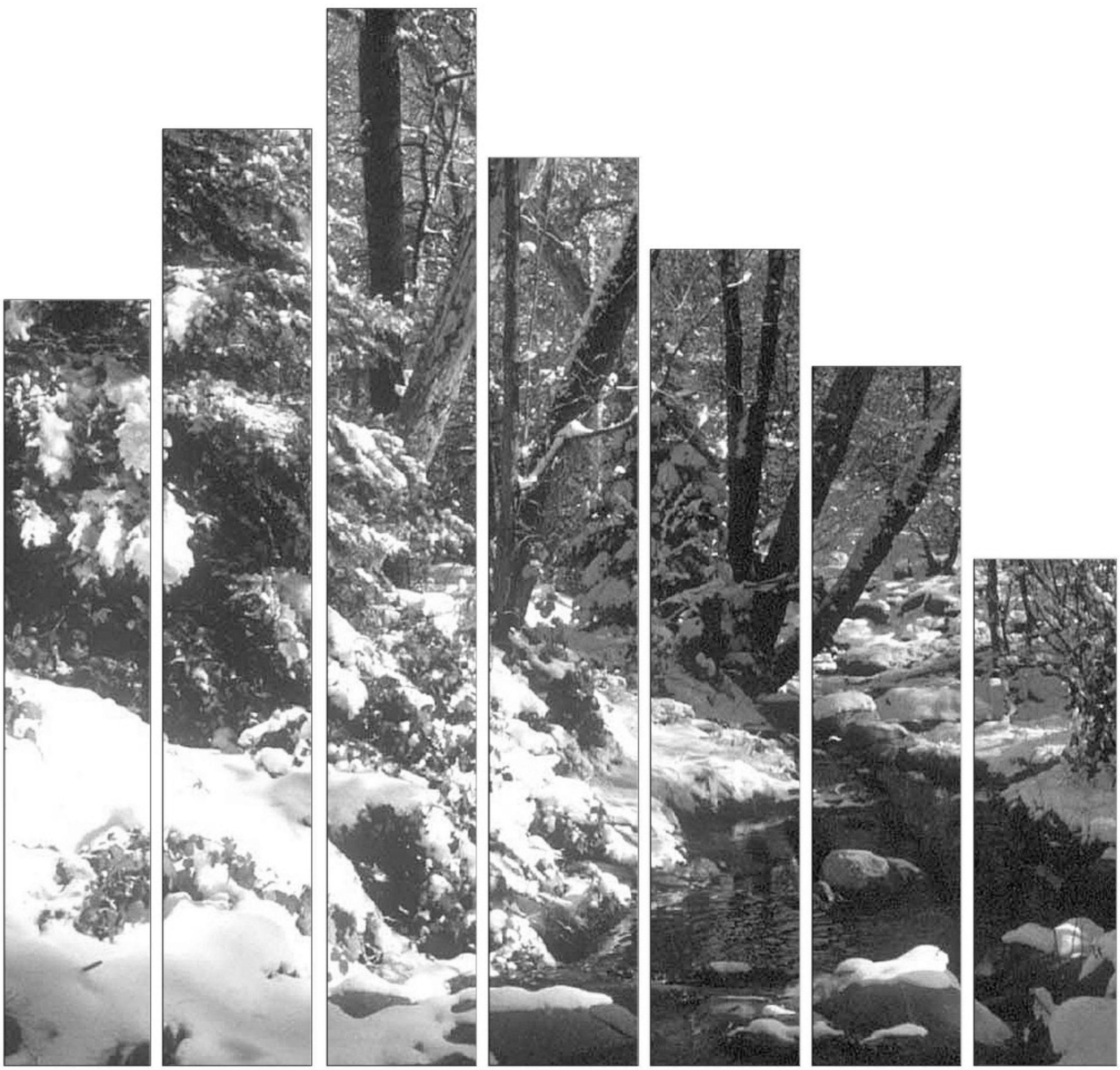
Snowpack-Runoff Relationships for Mid-Elevation Snowpacks on the Workman Creek Watersheds of Central Arizona

Gerald J. Gottfried
Daniel G. Neary
Peter F. Ffolliott



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Abstract—Snowpacks in the southwestern United States melt intermittently throughout the winter. At some mid-elevation locations, between 7,000 and 7,500 ft, snowpacks appear and disappear, depending on the distribution of storms during relatively dry winters. Some winter precipitation can occur as rain during warm storms and is not reflected in the snow course data. The USDA Natural Resources Conservation Service (NRCS) maintains a system of measuring stations to index snow conditions and predict snowmelt runoff.

The three Workman Creek watersheds in the Sierra Ancha Experimental Forest north of Globe were instrumented in late 1938 to study the hydrology of southwestern mixed conifer forests and to determine changes in streamflow and sedimentation resulting from manipulating the forest cover. The watersheds were deactivated in 1983, but they were re-instrumented in June 2000 after the Coon Creek wildfire to measure fire effects on forest hydrology and sediment dynamics. The Rocky Mountain Research Station would like to use NRCS data from the Middle Fork of Workman Creek to reinforce its hydrologic data acquisition and interpretation efforts. Snow water equivalent data can be used to characterize past winter runoff volumes and peak mean daily runoff. Significant regressions were developed between the data sets with coefficients of determination values ranging from 0.40 to 0.77. The relationships defined by these regressions will allow researchers and managers to ascertain the impacts of fire on snowmelt-related hydrologic processes and to estimate winter flows for the years when the installations were closed. They also provide an insight into the snowpack-runoff relationships for intermittent snowpacks that are common at intermediate elevations throughout Arizona.

Keywords —Snowmelt runoff, peak flows, volumes, forested watersheds, NRCS snow data, intermediate elevations, Arizona

The Authors

Gerald J. Gottfried and **Daniel G. Neary** are Research Forester and Research Soil Scientist, respectively, at the U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Flagstaff, AZ. Peter F. Ffolliott is a Professor, School of Renewable Natural Resources, The University of Arizona, Tucson, AZ.

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Introduction

Water availability is a critical issue for the continued development of the southwestern United States. Knowledge of streamflow timing is important to efficient impoundment and distribution. Snowmelt from higher elevation forested watersheds is a major source of runoff for most of the rivers in the western United States. Approximately 3.0 to 5.1 million acre-ft of water are stored in Arizona and New Mexico snowpacks before spring snowmelt (Ffolliott et al. 1989). However, snowpack conditions in the Southwest are variable; years of high and low snowpack accumulations are more common than average years. Southwestern snowpacks, unlike those in northern regions, melt intermittently throughout the winter. At some intermediate, mid-elevation locations (generally between 7,000 and 7,500 ft), the snowpack appears and disappears, depending on the distribution of storms, during relatively dry winters.

The relatively large number of wildfires that occurred throughout the southwestern United States in the year 2000 renewed interest about the effects of stand replacing fires on watershed characteristics and responses. In the early spring of 2000, the Coon Creek Fire overran the three Workman Creek watersheds within the Sierra Ancha Experimental Forest in central Arizona. The presence of the weirs, which had been deactivated in 1983, provides an opportunity to study the effects of this wildfire on peak flows, water quantity and quality, and sedimentation. This information is lacking in the Southwest, and its acquisition would allow managers to assess flood risks and to plan post-fire restoration and protection strategies in the future. It also could aid managers in estimating water yields from large burned areas. The Rocky Mountain Research Station and Tonto National Forest reopened the Workman Creek installation in June 2000 to obtain these data over a 5-year period.

The Workman Creek installations, including climatic stations, were operated from late 1938 through 1983. The USDA Natural Resources Conservation Service (NRCS), formally the Soil Conservation Service (SCS), has maintained a snow course and, subsequently, a snow telemetry station (SNOTEL) at Peterson Meadow within the Middle Fork of Workman Creek since 1951. This site, at 6,900 ft in elevation, serves as an index of snowpack dynamics in the Sierra Ancha Mountains, which are adjacent and northeast of Roosevelt Reservoir. Snow courses generally reflect snow conditions at higher elevations (Gottfried and Ffolliott 1981) and the Workman Creek snow course is representative of snowpacks at intermediate elevations. The Coon Creek Fire destroyed most of the old-growth forest on Middle Fork, which had served as the hydrological control for the various experiments. However, the area immediately adjacent to the NRCS station was not severely burned. Paired data were collected from the snow course and SNOTEL for a number of years until the snow course was deactivated in 1991.

The objective of this study was to determine the historical relationship between the NRCS snowpack data and (1) snowmelt runoff and (2) average flow rate for the day of maximum runoff. A statistically significant relationship could provide another tool for evaluating changes related to the fire and for predicting streamflow parameters for future snowmelt periods. The relationship also could be used to check if the fire influenced post-fire data from the NRCS station. It would be useful in interpreting the effects of past treatments and providing previously unavailable information about snowpack-runoff relationships for the Workman Creek watersheds. The streamflow information could be extrapolated to other mid-elevation watersheds where intermittent snowpacks occur.

Background

The Workman Creek snow course and SNOTEL station are part of a system that the NRCS maintains throughout the western United States to monitor snowpack conditions. SNOTEL stations collect snow and meteorological data and transmit them electronically to central locations. The NRCS snow courses and installations, which are usually located in forest openings, are representative of high mountain locations and provide an index of snow conditions within a river basin. Long-term snow course and related meteorological data are correlated with streamflow to predict future runoff from water stored in the snowpack. The snow survey effort in Arizona began in late 1937 to forecast streamflow in the Salt and San Francisco Rivers (Jones 1981).

In the late 1950s and 1960s, the USDA Forest Service's Rocky Mountain Forest and Range Experiment Station (now the Rocky Mountain Research Station) embarked on a watershed management research effort to evaluate the effects of a variety of vegetation management treatments on water yield augmentation, timber production, wildlife habitat, and livestock forage production (Baker 1999). Since snow is an important component of the hydrological regime in higher elevations, most of the forested experimental watersheds contained snow-sampling grids that usually were measured after major storms to determine peak accumulations. These experimental watersheds were often near NRCS snow courses and, in an earlier study, the snow course data were evaluated for their applicability to determine snow conditions, primarily snow water equivalents, on the experimental areas (Gottfried and Ffolliott 1981). The analyses showed that although there were differences in water equivalent measurements between NRCS and watershed snow data from a paired site, significant linear relationships existed between them. It was determined, therefore, that the snow course data could be used to describe snow conditions on adjacent watersheds. A subsequent analysis demonstrated that peak snow water equivalent data from the NRCS Hannagan Meadow snow course in the White Mountains of eastern Arizona could describe snowmelt runoff and the mean peak flows on the day of maximum streamflow for the adjacent experimental watershed on the East Fork of Willow Creek (Gottfried et al. 1997).

Studies were established in the Sierra Ancha Mountains in the 1930s to investigate the interrelated influences of climate and soils, topography and geology, and the effects of watershed vegetation on streamflow, soil erosion, floods, and sedimentation (Gottfried et al. 1999). Runoff and vegetation on the three forested Workman Creek watersheds were monitored to evaluate the impacts of several experimental and management treatments on the hydrology, sediment dynamics, and forest and forage resources. Unfortunately, intensive snow measurements and research studies on snowpack dynamics were not initiated at Workman Creek, because of the isolated location. The NRCS data were not used to interpret watershed experiments at Workman Creek.

Study Area

The Workman Creek watersheds are part of the Sierra Ancha Experimental Forest, which is located within the Salt River drainage, about 30 mi north of Globe, on the Tonto National Forest. The three watersheds—North Fork (248 acres), Middle Fork (521 acres), and South Fork (318 acres)—were instrumented in 1938 to study the hydrology of mixed conifer forests and to determine changes in streamflow and sedimentation as a result of manipulating the forest vegetation (Rich and Gottfried 1976). The area is between 6,590 and 7,724 ft in elevation. The NRCS snow course received an average of about 36.2 inches of annual precipitation between 1960 and 1991 (Martinez 1993); two-thirds of the annual precipitation falls during the October through May period, mostly as snow, although heavy winter rain or rain-on-snow events occur, and the remainder comes during the summer monsoon period (figure 1). The three wettest months are December, March, and January and the driest months are May and June. The undisturbed forest cover consisted of ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and white fir (*Abies concolor*), with minor amounts of aspen (*Populus tremuloides*) and Gambel oak (*Quercus gambelii*). New Mexican locust (*Robinia neomexicana*) was a prevalent understory species.

Perennial streamflow was recorded continuously at 90° V-notch weirs at North Fork and South Fork and a combination 90° V-notch weir and 7-ft Cipolletti weir at Main Dam below the confluence of the three catchments. The Main Dam measures streamflow from the entire 1,087 acres. The differences between Main Dam and the other two stations determined Middle Fork runoff. Prior to treatments, average annual runoff ranged from 3.41 ± 0.47 inches at South Fork to 3.20 ± 0.82 inches at Middle Fork. A 3-ft trapezoidal flume was constructed below the main 411-acre section of Middle Fork in July 1952, near its confluence with South Fork and North Fork. The flume was operated from water year 1953 through 1972 and from 1977 through 1983. A water year is the period from October 1 through September 30. A weather station that was located in Peterson's Meadow to the north of the NRCS snow course was reestablished after the Coon Creek Fire.

Past Treatments and Results

A review of the past treatments and results of watershed research at Workman Creek is helpful in placing this study into perspective. One objective for developing the snowpack-runoff relationships between

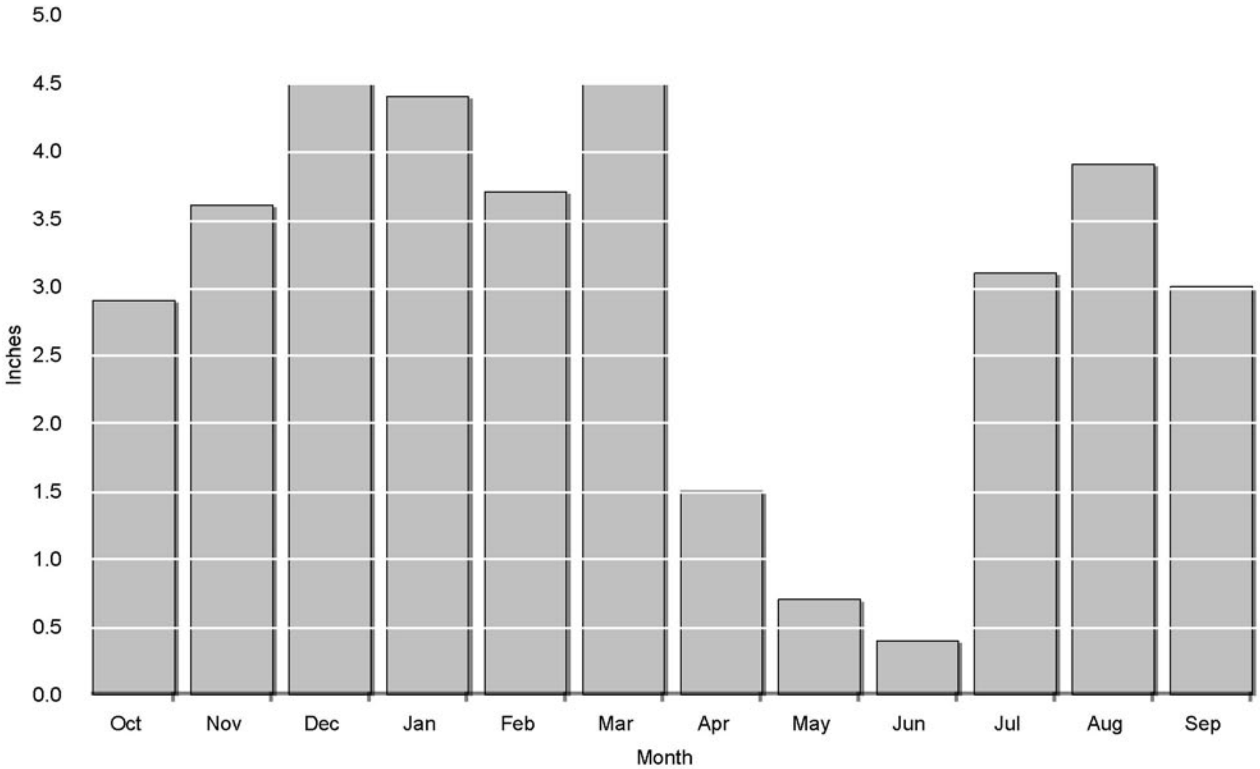

Figure 1—Average precipition from 1961 to 1990 at the NRCS Workman Creek snow measurement site (from Martinez 1993).

the NRCS and Workman Creek data is to provide a basis for interpreting the impacts of previous experimental treatments on streamflow parameters, especially for the period when the installations were deactivated. The different treatments also are affecting current streamflow.

North Fork

The objective on North Fork was to determine the potential of increasing water yields by removing the forest and converting to a grass cover in a series of steps (Rich and Gottfried 1976; Gottfried et al. 1999). The treatments were experimental and selected to cover a range of possible manipulations. The first treatment was implemented in 1953 when riparian trees, such as Arizona alder (*Alnus oblongifolia*) and bigtooth maple (*Acer grandidentatum*), were cut along the stream channels. This cut removed 0.6% of the watershed's basal area. The next treatment, in 1958, converted the moist-site forest vegetation, mostly Douglas-fir and white fir, to grass on about 80 acres nearest the channel. Large trees were harvested and smaller trees and unmerchantable material were windrowed and burned. Cleared areas were seeded with grass species.

The final treatment, in late 1966, was the harvesting of the dry site forest, primarily ponderosa pine, on 100 acres. A prescribed fire was used to remove residual trees, and the area was seeded with grasses. Locust and Gambel oak became established on many sites within the watershed.

Streamflow increased significantly ($\alpha = 0.05$) from both the moist- and dry-site treatments, but not from the 1953 riparian treatment. The moist-site treatment resulted in an increase of 42 ± 10% or 1.26 ± 0.29 inches and the dry-site treatment resulted in an increase of 31 ± 9% or 1.32 ± 0.37 inches (Rich and Gottfried 1976). The combined effect was an increase of 84 ± 11% or 2.70 ± 0.35 inches. Hibbert and Gottfried (1987) determined that the increases remained stable for 13 years following treatment. The Coon Creek Fire resulted in low to moderate burn severities on North Fork, although some of the forested areas had high burn severities.

South Fork

The first treatment on South Fork was designed to test a common forest management prescription for the time. The watershed was harvested in 1953 according to a standard single-tree selection prescription. In 1957, a wildfire burned 60 acres near the top of the watershed. A total of 45% of the original basal area on South Fork was removed in these two events. The objective of the second treatment, in late 1966, was to convert the mixed conifer vegetation to a pure ponderosa pine stand by removing other tree species and planting pine seedlings. Larger trees of all species were harvested and residual pine stands were thinned. The residual ponderosa pine stands were to be maintained at 40 ft^2/acre to determine if this density would optimize both timber and water production.

The single-tree selection method produced a small but significant increase in runoff, about 7 ± 6% or 0.23 ± 0.20 inches. The results of the attempted conversion to a pure ponderosa pine stand were similar to the water yield increases from North Fork. The increase was 111 ± 16% or 3.67 ± 0.52 inches (Rich and Gottfried 1976). The increases were sustained during the 13 years used in the last data analysis (Hibbert and Gottfried 1987). The watershed currently contains a mixture of ponderosa pine small sawtimber, poles, and seedlings, and locust and oak trees. Burn severities caused by the Coon Creek Fire were low to moderate, although some planted ponderosa pine stands were destroyed.

Middle Fork

Middle Fork was reserved as the control watershed, since the standard paired watershed design was being used to quantify changes in streamflow related to treatments on the other two watersheds (Gottfried et al. 1999). The Middle Fork was severely burned in the Coon Creek Fire. A post-fire survey indicated that most of the trees had been killed or severely damaged and that the duff layer and most slash had been consumed.

Implications of Past Research

The Workman Creek experiments bracketed the water yield increases possible through a range of vegetation treatments. Increases were achieved by replacing deep-rooted trees with shallower-rooted grasses, shrubs, and tree seedlings that utilized less water. Less water was withdrawn and less precipitation was needed to recharge the soil resulting in an earlier and more efficient movement of water into the stream channels. While many of these treatments would not be considered for present day management, the results from Workman Creek provided guidance for subsequent watershed research that evaluated multiresource prescriptions, which removed fewer trees or created smaller openings, and provided managers and researchers with information about the implications of management on the water resources (Gottfried et al. 1999).

Methods

Field Procedures

Snowpack water equivalent (SWE) and depth data, measured in inches, were collected with a federal snow sample tube on the NRCS snow courses. SNOTEL data are not used since collections began at the end of the study period. The NRCS conducts snow surveys every 2 weeks from January 15 through April 1. Additional surveys are made earlier or later if snowpack conditions warrant them. The typical snow course contains 5 to 10 measurement points spaced at 25 to 50 ft intervals along a transect line. Although peak accumulations could occur between measurement dates or a snowpack could melt and re-accumulate between dates, the NRCS data provide good indications of peak snowpack conditions because of frequent sampling.

Analytical Procedures

The analyses are based on the NRCS snow course and Rocky Mountain Research Station streamflow data from 1953 through 1979. The analysis for the Main Dam utilized all 27 years of data, while the analysis for the Middle Fork flume utilized 21 years of data, from water years 1953 through 1979; water years 1954 and 1958 were not included because of incomplete data, and the flume was not in operation from water year 1973 through 1976. Data from the North and South Forks were analyzed to determine if the NRCS data also could be used to evaluate changes on these watersheds since the fire. Only data for the 13 years between the last treatments and 1979 were used because changes resulting from the earlier treatments might confound the analysis.

Peak snow water equivalent (SWE) data for the snow course were obtained from a summary of SCS snow survey records (Jones 1981). This publication also provides snow depth and dates of peak accumulation information. Since the snow course is no longer measured by the NRCS, an analysis was conducted to confirm that SNOTEL and snow course peak snow water equivalent data were similar. Nine pairs of annual peak or high SWE measurements from 1981 through 1989 were compared. The analyses confirmed that SNOTEL data could be used as a proxy for snow course data for future analyses. If a longer series of SNOTEL data is needed, SNOTEL values for previous years can be estimated by the regression that has been forced through zero:

$$\text{SNOTEL} = 0.44(\text{Snow Course})^{1.37}$$

The regression has a coefficient of determination (r^2) of 0.94 and a standard error of 1.34 inches. This relationship is specific to the Workman Creek situation, and may be of limited usefulness in other locations. Individual analyses should be conducted to extend the data at other locations where SNOTEL installations have replaced snow courses.

Runoff data were obtained from the records on file with the Rocky Mountain Research Station, Flagstaff, Arizona. Snowmelt runoff quantities started from the estimated date of peak water equivalent accumulation through June 30. This period includes the runoff months of April and May and all or a part of February and March, depending on when peak occurs. June was included because baseflow from the deep soils on the watersheds is primarily derived from snowmelt, although some early summer rain events can occur. Occasionally, peak streamflows occurred before peak SWE was measured; rain-on-snow events or rain during unusually warm weather have contributed to some large peaks. Snowpacks tend to fluctuate more at mid-elevation sites, such as Workman Creek, than at higher elevations and often will be intermittent through a winter. The mean daily flow rate in cubic feet per second (cfs) for the day with the highest flow was determined from the records. Short duration high peaks on days of low flows were not considered. Calculations for the snowmelt period included runoff efficiency, which is defined as the proportion of runoff relative to peak water equivalent (Solomon et al. 1975).

Regression models were estimated to evaluate the relationships between snowmelt runoff parameters and peak snow water equivalents. Regression models with multiple predictors were considered, but a simple linear regression model gave similar or better results than more complicated models. Data were checked for outliers and normality by standard procedures. Statistical significance was interpreted and confidence intervals were estimated assuming $\alpha = 0.05$. Adjusted r^2 values are presented to characterize model goodness-of-fit. Since vegetation manipulations on North Fork and South Fork during the 27 years influenced runoff measured at Main Dam, multiple linear regression models were calculated to estimate whether time influenced the relationships with snow water equivalents. A time factor representing the number of years since the start of the data set and an interaction value of time and snow water equivalent, following the procedure discussed by Baker (1986), were evaluated; however, the time factors were not significant in the Workman Creek analyses. Means are presented with standard errors.

Results and Discussion

Precipitation and Runoff

The 27-year study period included some of the wettest and driest years that have been measured at Workman Creek. The average date of peak snowpack accumulation between 1953 and 1979 was February 15, when an average of 5.2 ± 0.8 inches of water were measured (figure 2); however, the peak occurred on January 15 in 6 years and on April 1 in 1 year (1979). The greatest peak snow water equivalent (20.1 inches) occurred on March 15, 1973, while the smallest (1.2 inches) occurred on January 15, 1972. Snow was measured on every early February visit, while the snow course was bare during 56% of the early April visits. Annual runoff averaged 4.61 ± 0.88 inches for Main Dam (1953–1979) and averaged 2.77 ± 0.73 inches at the Middle Fork flume for the period of record being evaluated.

Snowmelt Runoff and Peak Snow Water Equivalent

Main Dam

A simple linear regression model was estimated between snowmelt runoff and peak snow water equivalent (table 1, figure 3). Peak SWE averaged 6.98 ± 0.97 inches during the period, while snowmelt runoff averaged 1.97 ± 0.34 inches. The highest runoff was in 1973 with 9.19 inches and the lowest year was 1955 with 0.32 inches. Annual precipitation in 1973, 60.9 inches, was the highest year on record. Snowmelt runoff in 1973 accounted for 51% of the 18.0 inches annual runoff from the three Workman Creek watersheds.

Middle Fork Flume

A simple linear regression model was also estimated between snowmelt runoff and peak snow water equivalents (table 1, figure 4). Snowmelt runoff averaged 1.30 ± 0.38 inches for the 21 years. The highest value on record was 7.62 inches in 1968; and the lowest year was 0.03 inches in 1972. The flume was closed down in 1973.

North Fork and South Fork

The regression relationships between peak SWE and snowmelt runoff for both watersheds for the 13-year post treatment periods were significant (table 1). If future snow accumulations are unaffected by the fire, these equations could be used to determine cumulative changes related to vegetation growth and the fire on the two watersheds. Snowmelt runoff values for the missing years could be calculated if the post-fire relationships were similar to those for the 13-year treatment periods.

Peak Mean Daily Runoff and Peak Snow Water Equivalent

Main Dam

A significant linear relationship did not exist between mean streamflow rates for the day of highest yearly

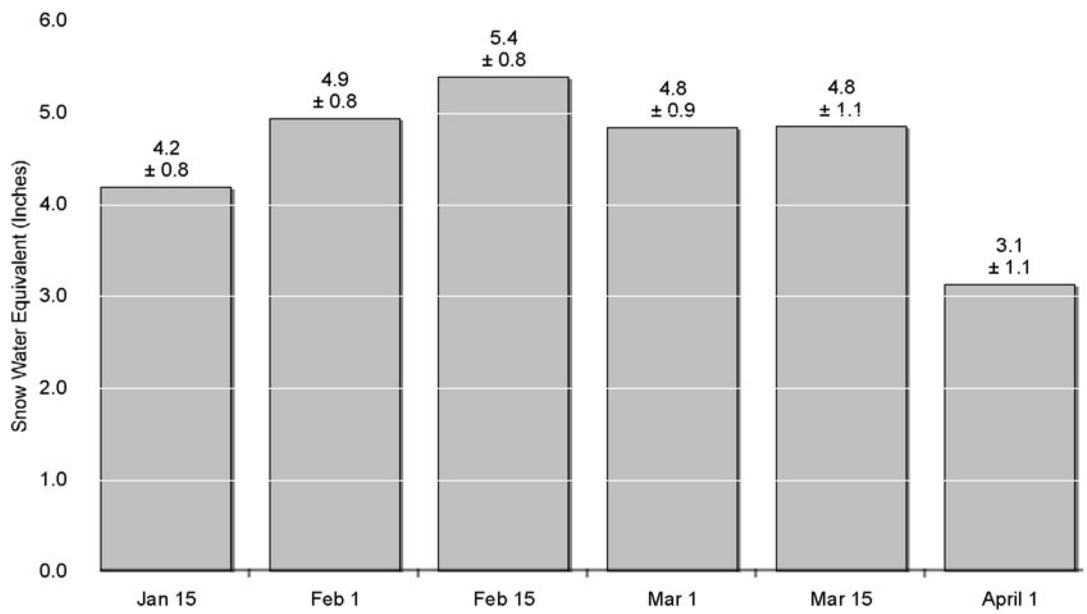

Figure 2—Average snow water equivalent (with standard errors) by measurement date for the Workman Creek snow course for 1953 through 1979.

snowmelt runoff and peak snowpack water equivalent (SWE) at the Workman Creek snow course. This result was primarily attributed to the peak flow of over 49 cfs in 1954 when only 4.6 inches of peak snow water equivalent were measured. The peak occurred during a storm period that extended from March 21 through 26 and produced 10.8 inches of precipitation. The snow course was bare on March 15 and contained 1.2 inches of water on April 1. Temperature records are not available, but this could have been a rain-on-snow or a rain event. If the 1954 record is removed from the analysis, a significant relationship can be developed (table 1). The average peak flow for the day of greatest runoff, excluding 1954, was 4.51 ± 0.82 cfs; the highest value was 16.12 cfs in 1973 when 20.1 inches of water were measured in 60 inches of snow depth. The lowest flow was 0.34 cfs in 1972 when the snow survey indicated 1.2 inches of water in 4 inches of snow on January 15. During the 27 years of record, 2 peak days were in January, 5 in February, 13 were in March, and 7 were in April. Future analyses might be useful to evaluate the relationships among peak

Table 1—Significant regressions between snowmelt runoff (runoff) or peak flows (peak) and snow water equivalents (SWE) at Workman Creek. Runoff and SWE are measured in inches and peak flows are measured in cubic feet per second.

Watershed	Regression	Adjusted r^2	Standard error
Snowmelt Runoff			
Main Dam	Runoff = 0.12 + 0.26 (SWE)	0.54	1.22
Middle Fork	Runoff = –0.71 + 0.31 (SWE)	0.70	0.96
North Fork (1967–1979)	Runoff = 0.34 + 0.35 (SWE)	0.77	1.16
South Fork (1967–1979)	Runoff = 0.58 + 0.45 (SWE)	0.77	1.50
Peak Mean Daily Runoff			
Main Dam (wo/1954)	Peak = 0.75 + 0.53 (SWE)	0.40	3.22
Middle Fork	Peak = –0.60 + 0.32 (SWE)	0.62	1.17
North Fork (1967–1979)	Peak = 0.05 + 0.23 (SWE)	0.62	1.06
South Fork (1967–1979)	Peak = –0.78 + 0.44 (SWE)	0.54	2.39

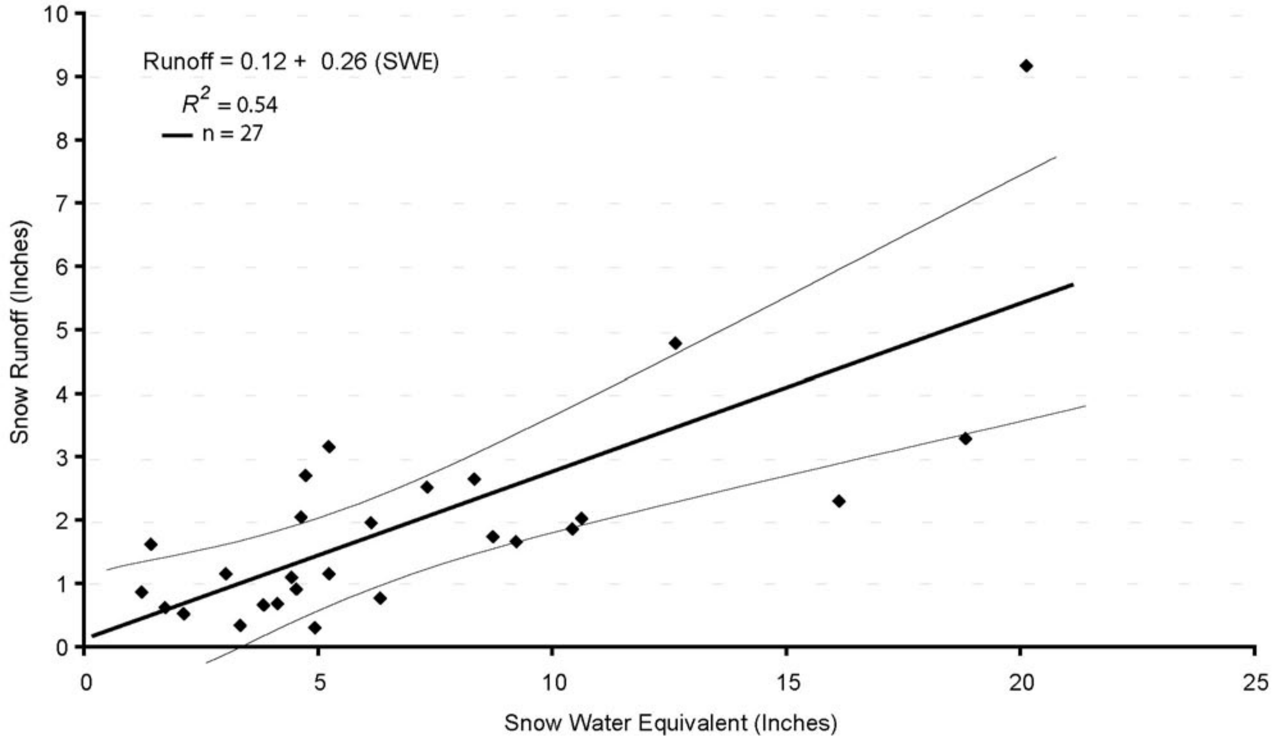

Figure 3—The relationship between snowmelt runoff at the Main Dam of Workman Creek and peak snow water equivalent from the NRCS site. Regression includes the 95 percent confidence band.

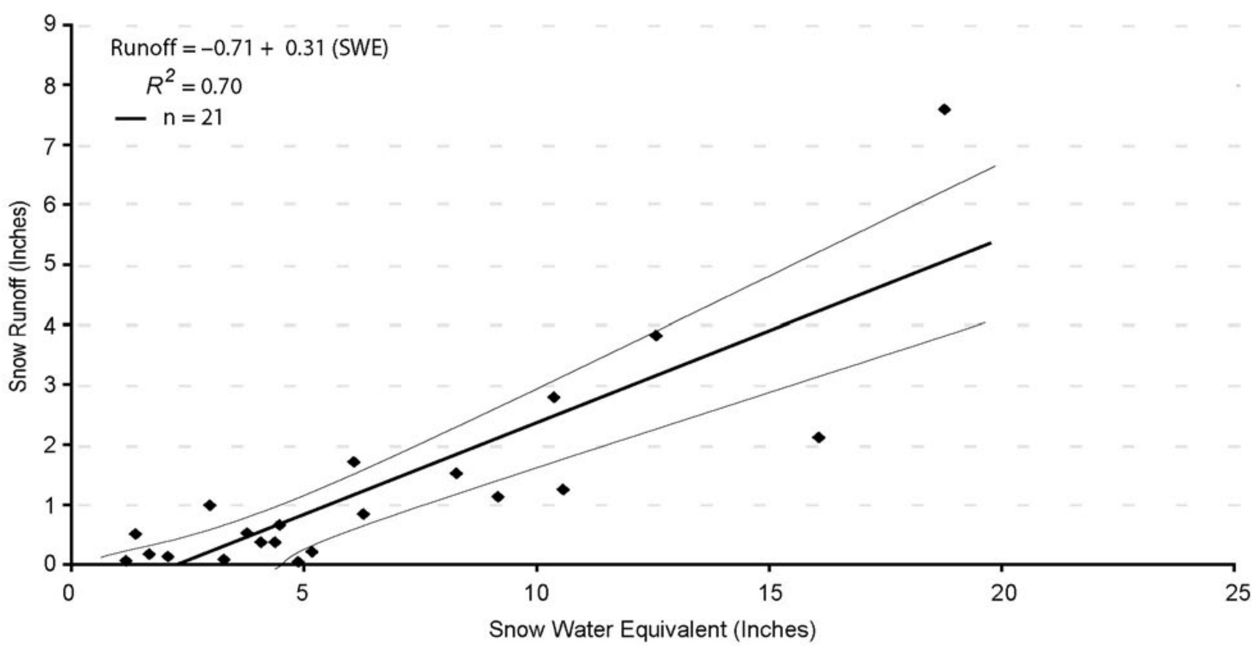

Figure 4—The relationsip between snowmelt runoff at the Middle Fork flume of Workman Creek and peak snow water equivalent from the NRCS site.

flows, snow water equivalent, solar radiation, and temperatures and the role of antecedent soil water conditions.

Peak daily snowmelt flow is significantly related to snowmelt runoff volume when the 1954 data are not included. The regression has an adjusted r^2 of 0.74 and a standard error of 2.14.

Middle Fork Flume

A simple linear regression relationship was estimated between peak snow water equivalent and the peak flows at the Middle Fork Flume (table 1, figure 5). The mean was 1.48 ± 0.42 cfs and the values ranged from 7.33 cfs in 1968 to 0.03 cfs in 1972. The earliest peak flow was on January 12 and the latest peak was on April 17; 3 peak days during the analysis period were in January, 3 in February, nine in March, and 4 in April.

North and South Forks

Regression models were estimated between peak mean daily flows and SWE for the treated watersheds for the 1967 through 1979 water years (table 1).

Runoff Efficiency

Main Dam

Runoff efficiency is related to antecedent soil water, temperature, and precipitation patterns; it appears independent of SWE. Significant regressions were not present between maximum snow water equivalents and runoff efficiency. The average efficiency was 32.6 ± 4.5%. Efficiencies ranged from 6.6 to 117.1%; the highest reading of over 100% in March 1970, could be related to a rain event, since 6.3 inches of moisture were measured that month. The peak snowpack in 1970 was measured in January.

Middle Fork Flume

A significant linear relationship was not present for efficiency measured at the flume. The mean was 16.6 ± 2.6%, and the range was from 1.3 to 40.5%. The runoff efficiency in 1970 was 38.1%.

Workman Creek Compared to Willow Creek

It is interesting for watershed managers to compare results from Workman Creek with a similar set of analyses conducted on data from the higher elevation Willow Creek East Fork and the Hannagan Meadow snow course. Willow Creek is located between 8,800 and 9,300 ft in elevation, where an average of 34.4 ± 7.6 inches of precipitation has been measured (Gottfried et al. 1997). The values for both snowmelt runoff and peak snowmelt runoff were determined in the same manner as for Workman Creek. The analyses produced

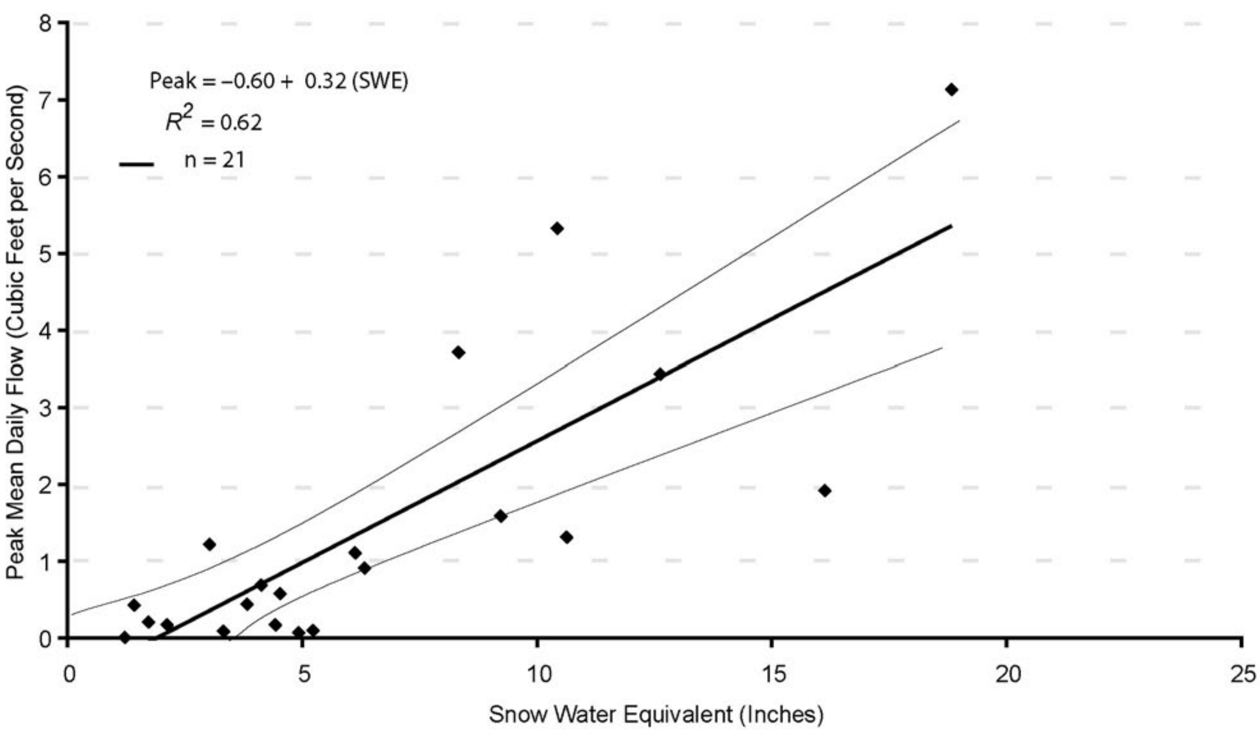

Figure 5—The relationship between mean peak for the day of peak flow at the Middle Fork flume of Workman Creek and peak snow water equivalent from the NRCS site.

a linear regression for snowmelt runoff with a coefficient of determination of 0.87 and a linear regression for peak runoff within an r^2 of 0.72. Both of the relationships explain more of the variation than do the relationships for Main Dam and Middle Fork of Workman Creek. One explanation for the difference is that these higher elevation sites experience less melting during the winter than do the lower elevation Workman Creek sites. The average snowmelt efficiency at Willow Creek was 61.5 ± 3.5% compared to 32.6% for Main Dam and 16.6% for Middle Fork. Snowpack conditions at Willow Creek are less likely to fluctuate as much as the snowpack at Workman Creek, which is more intermittent because of warmer air temperatures and has the potential for more rain-on-snow events or rain events that would occur as snow at higher elevations. The difference in precipitation form is probably the cause of the high peak in March 1954 and the high efficiency in 1970. The differences in precipitation form were observed during some of the warm storms that passed through Arizona during the late 1970s when it rained at Workman Creek and snowed at Willow Creek.

Conclusions

Watershed managers should understand snowpack dynamics and have the ability to predict the characteristics of snowmelt-generated streamflows. Managers often rely on the NRCS snow data as an index to forecast winter runoff in downstream areas. However, there is little documentation about the use of NRCS information to predict runoff values from headwater areas.

This study shows that statistical relationships exist between peak snowpack accumulations and snowmelt runoff quantities or resulting peak mean daily flows for the Main Dam and Middle Fork installations at Workman Creek for the period of available record. Similar relationships also exist for the last treatment period on the North Fork and on the South Fork watersheds. These relationships could enable researchers and managers to ascertain the impacts of the Coon Creek Fire on snowmelt related hydrologic processes and provide a check on the impact of the fire on data from the NRCS station. The use of statistically similar snowmelt runoff relationships between the last treatment period and the post-fire period on North Fork or South Fork provides a method of estimating winter flows for the years when the installations were closed. The analyses also increase our basic knowledge of the hydrology of the Workman Creek watersheds.

Further testing is necessary to confirm how well these relationships can be used to predict other hydrological parameters. An examination of other NRCS snow course-watershed runoff data sets could confirm the basic form of these relationships and possibly allow their extrapolation to similar adjacent ungaged watersheds, especially where intermittent, mid-elevation snowpacks occur. Watershed managers could use this information to determine the effects of snowmelt runoff on stream channels, riparian vegetation, fishery resources, and status of mountain lakes and ponds. These data also could be used in the development and testing of computer simulation models designed for predicting snowmelt runoff from headwater watersheds.

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Rocky Mountain Research Station
240 West Prospect Road
Fort Collins, CO 80526

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*Station Headquarters, Natural Resources Research Center, 2150 Centre Avenue, Building A, Fort Collins, CO 80526