PATTERNS AND TRENDS IN STREAMSLOW FROM 1939 TO 1980 AT WORKMAN CREEK, SIERRA ANCHA EXPERIMENTAL FOREST, ARIZONA

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Water is a vital natural resource and its paucity in the Southwest makes it of particular importance. There is a long history in the Southwest of research on increasing water yields from forests starting in 1911 at Wagon Wheel Gap Experimental Watershed in central Colorado. Watershed studies in the Salt River Basin began in 1925 with the Summit Plots upstream from Roosevelt Dam. The Summit Plots were established to study the effects of vegetation change and mechanical stabilization on stormflows and sediment yields after it was discovered that 101,000 acre-feet of sediment had accumulated behind Roosevelt Dam in less than two decades (Gottfried et al. 1999). Watershed studies at Workman Creek were initiated in 1938 to investigate the hydrology of mixed conifer forests and determine the effects of manipulating these forests to increase water yields. Streamflow was monitored from 1939 to 1980 at the four gaging stations.

Two watersheds, North Fork, and South Fork, were instrumented with 90° V notch weirs. Main Dam, located downstream of the confluence of the other three watersheds was instrumented with a compound weir consisting of a 90° V-notch weir and a 7-ft Cipolletti weir. The flows of Middle Fork were calculated as the difference between Main Dam and the two other catchments. The objective of the treatments on North Fork was to determine the water yield increases possible from converting a mixed conifer forest cover into a cover of herbaceous plants in stages. The objective of the treatments on South Fork was to determine the hydrologic effect of forest management practices as conducted in the 1950s and 1960s. Middle Fork was the control. The watersheds were calibrated 13 years prior to treatment.

SITE DESCRIPTION

The Workman Creek watershed is located in Central Arizona approximately 30 miles north of Globe in the Sierra Ancha Experimental Forest. The climate at the site is characterized by two wet seasons; one in winter that receives approximately 67 percent of the annual precipitation and the other in summer receives approximately 33 percent of annual precipitation. Precipitation measured on Middle Fork from 1938 through 1973 averaged 32.89 inches annually. Winter precipitation (October-May) averaged 22.01 inches while summer precipitation (June-September) averaged 10.88 inches (Rich and Gottfried 1976). The elevation ranges from 6590 to 7724 feet. The basin drains to the west and is divided into three catchments varying in size from 248 to 521 acres in size, each with a perennial stream (Rich et al. 1961).

Soils are loam to clay loam in texture and granular to crumb in structure. Subsoils are layered and vary in texture from clay loams to clay. Soil depth ranges from a few inches to 15 feet. Soils rest on Dripping Springs quartzite with intrusions of diabase and basalt plugs and sills (Rich et al. 1961).

The pre-treatment forest on the watershed was mixed conifer with ponderosa pine (*Pinus ponderosa*) being the most common tree, especially on the drier sites. Douglas-fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*) were more common on the wetter sites. The understory shrubs consisted of mostly New Mexican locust (*Robinia neomexicana*) and Gambel oak (*Quercus gambelii*). Riparian trees found sparsely along the stream channel consisted of bigtooth maple (*Acer grandidentatum*), Arizona alder (*Alnus oblongifolia*), Arizona walnut (*Juglans major*), and aspen (*Populus tremuloides*). Table 1 presents proportions of trees by species on the three watersheds. There is a 20-acre meadow on Middle Fork and a 2-acre meadow on South Fork. Other than these two meadows, the herbaceous cover was less than 1 percent of the original ground surface (Rich et al. 1961).

FOREST TREATMENTS AND PREVIOUSLY REPORTED RESULTS

North Fork Watershed Treatments

The treatments on North Fork were designed to determine water yield increases possible in mixed

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Table 1. Proportions of trees by species on the three watersheds within Workman Creek.

Watershed	Total area (acres)	Ponderosa pine	White fir	Douglas fir	Gambel oak	Other	Basal area (ft^2/acre)
		Average tree composition					
North Fork	248	52.3%	20.1%	4.1%	22.2%	1.4%	174
Middle Fork	521	46.4%	20.2%	10.1%	21.8%	1.5%	193
South Fork	318	59.4%	25.5%	5.8%	8.0%	1.3%	201
Total	1087	53.0%	22.0%	7.0%	17.0%	1.0%	191

conifer forests by changing the cover type to grass. The trees on the watershed were removed in a series of steps from the riparian vegetation component, mixed conifer component, and ponderosa pine component, respectively. The first treatment removed riparian trees, mainly Arizona alder and bigtooth maple, from around the stream channels, seeps, and springs. After the trees were cut, the stumps were coated with herbicides to prevent subsequent sprouting, a common regeneration strategy for these species. The riparian cut removed 0.6 percent of the total basal area of North Fork, with no statistically significant increase in annual water yield when compared to the control watershed. However, the treatment did increase summer stormflows and peaks by up 280 percent for rainfall events larger than 2 inches in the 5-year period following treatment (Hibbert and Gottfried 1987).

The second treatment on North Fork converted the moist-site mixed conifer forest, predominantly Douglas-fir and white fir trees, to grass and other herbaceous plants. About 80 acres, approximately 32 percent of the watershed, was clear-cut in 1958. This treatment resulted in water yield increases of 42 percent or 1.26 inches for average conditions (Rich and Gottfried 1976). Increases of 322 to 442 percent were observed for summer stormflows and peaks for storms of 1 to 2 inches. Modest increases in stormflow of approximately 30 percent were reported for winter storms. The percent increases were smaller for winter storms than summer storms but had larger volume increases in water yield (Hibbert and Gottfried 1987).

The third treatment on North Fork converted the 100-acre dry site, predominantly ponderosa pine although Douglas-fir and white fir were also represented, to grass and other herbaceous plants. The timber harvest of about 100 acres was completed in the fall of 1966. A prescribed fire during the winter of 1969 removed much of the remaining stand. The surviving trees were treated with herbicide, completely clearing the stand. This treatment increased water yield 1.32 inches (Rich and Gottfried 1976). Summer stormflows and peaks were similar to the moist site treatment (Hibbert and Gottfried 1987). The combined effect of the treatments was an increase of 2.7 inches or 84 percent in annual streamflow (Rich and Gottfried 1976). The water yield increases remained stable of 13 years (Gottfried et al. 1999).

South Fork Watershed Treatments

The treatments on the South Fork were designed to determine the effects of managing a forested watershed for the production of high-quality timber on water yield and sedimentation. Only the water yield results are discussed in this paper.

The first treatment, a single-tree selection, started in June 1953 and ended in November 1955, reduced the basal area of the forest by 24 percent. The stand-improvement portion of the treatment began in 1956. Small areas of pine infested with mistletoe were treated with herbicide and larger stands were isolated using herbicides to create 60-foot buffers. Gambel oak, New Mexican locust, and firs, which were determined to be competing with pine, were also removed (Rich et al. 1961). These actions reduced basal area a further 6 percent. A wildfire in 1957 burned the 60 acres on the southeast section of the watershed, removing another 9 percent of the total basal area. Other damage associated with logging (i.e., construction of access roads and skid trails) reduced the basal area by 6 percent. All told, basal area was reduced 45 percent. The increases in water yields were statistically significant but of little practical importance (Rich and Gottfried 1976). Summer stormflows and peaks increased "most dramatically" in the two summers following the wildfire. Stormflow volumes increase 2.5 to 3 times, while stormflow peaks increased 5 to 10 times. However, after two summers, stormflow volumes and peaks returned to near pretreatment levels (Hibbert and Gottfried 1987).

The second treatment on South Fork took place in 1966. Before implementation of this treatment, basal area on the watershed was 118 ft^2 /acre. Merchantable timber was removed and the remaining trees were thinned to a density of 40 ft^2 /acre. Areas infested with dwarf mistletoe and areas of fir were cleared, windrowed, and burned. About 55 acres of thinned pine remained following this treatment, with the rest of the watershed mostly cleared. Reforestation efforts were largely frustrated by plant competition and activities of pocket gophers (Thomomys bottae). This treatment significantly increased water yield (Rich and Gottfried 1976). Summer stormflows and peaks were less responsive than the selection cut treatment, except for storms of less than 1.5 inches in which case the responses were about equal. A minor increase in winter stormflows and peaks were attributed to the treatment (Hibbert and Gottfried 1987).

The combined these treatments produced an increase in water yield of 111 percent or 3.67 inches that was sustained for 13 years (Gottfried et al. 1999, Rich and Gottfried 1976). Table 2 summarizes all of the treatments.

The weirs were de-commissioned in 1980 due to the U.S. Forest Service shifting their priorities (Gottfried et al. 1999). However, the weirs were reactivated after the Coon Creek Fire of 2000, a 9,644-acre fire, burned the three watersheds (Gottfried et al. 2003). The patterns and trends in streamflow at the Main Dam from 1939 to 1980 are described in this paper.

METHODS

Workman Creek streamflow data-sets were obtained from archived files at the Rocky Mountain Research Station Flagstaff Laboratory. Each water year was a complete file of daily and monthly summaries. To make the Sierra Experimental Forest legacy data available (via the Rocky Mountain Research Stations website1), the annual summaries of monthly streamflow between 1939 and 1980 were digitized into Excel for ease of analysis and integration.

After digitization, the yearly, seasonal (winter and summer), and monthly means of streamflow were calculated for a given water year. A water year (WY) spans October 1 through September 30 of the following year and is named for the year in which it ends, that is, WY 1939 is from October 1, 1938, through September 30, 1939. Winter flows occur between October 1 and May 31, while summer flows between June 1 and September 30 for a given year.

Precipitation data were obtained from the Western Regional Climate Center. These data were collected at a site that is approximately 3 miles from Main Dam and about 1400 feet lower in elevation. Though there is a discrepancy in elevation, this was the closest gauging station with long-term records for use in determining trends in streamflow at Workman Creek.

RESULTS AND DISSCUSSION

Average yearly runoff at Workman Creek from 1939 to 1980 was 4.53 inches. The lowest annual runoff of 0.94 inches was recorded in 1955, while the highest annual runoff of 18.36 inches was recorded in 1980 (Figure 1).

Table 2. Treatment types and application dates on the North Fork and South Fork watersheds of Workman Creek (Rich and Gottfried 1976). Middle Fork was the untreated control.

	Treatment	Year	Area treated (acres)	
North Fork	Riparian Cut	1953	1.50	0.6%
	Moist Site Cut	1958	79.36	32%
	Dry Site Cut	1966	99.2	40%
	Treatment	**Year**	**Basal area removed (ft^2/acre)**	
South Fork	Single Tree Selection	1953-1955	72.36	36%
	Wildfire	1957	18.09	9%
	Thinning treatment	1966	70.35	35%

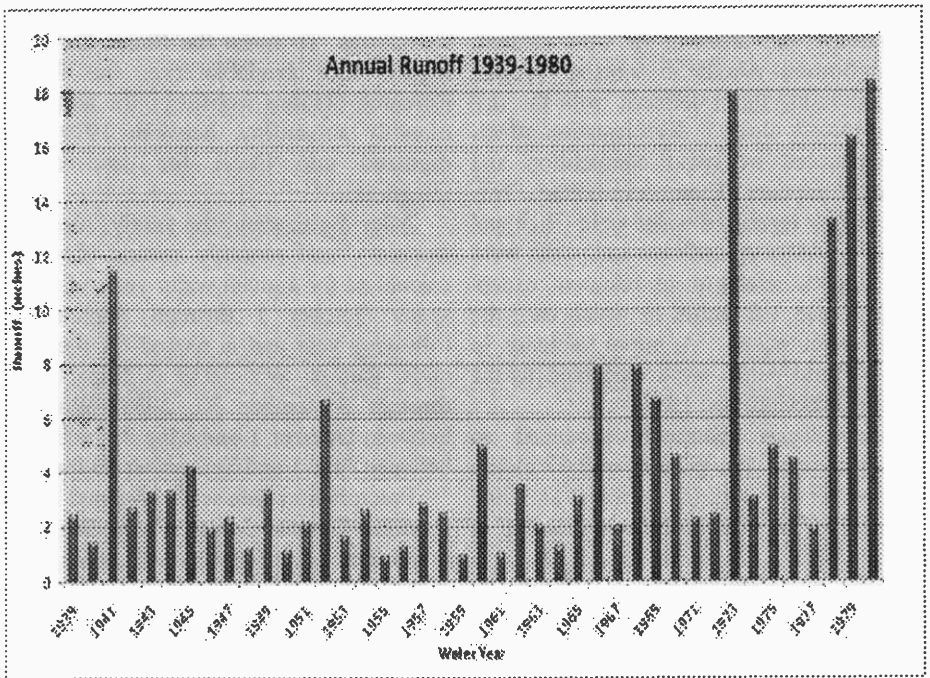

Figure 1. Total yearly runoff at Main Dam of Workman Creek from 1939-1980.

A comparison of average monthly precipitation and runoff at Workman Creek is shown in Figure 2. The general bimodal precipitation pattern of the region and the occurrence of the peak runoff volumes throughout the winter and early spring months on Workman Creek are illustrated by this figure.

Due to the bimodal precipitation pattern of this region, the data were lumped into winter runoff and summer runoff. Winter runoff accounted for 89 percent of total runoff and winter precipitation for 66 percent of total yearly precipitation. Summer runoff was 11 percent of total yearly runoff and summer precipitation was 33 percent of annual precipitation. These data sets indicate that winter precipitation was the "primary driver" of runoff. The relationship between total runoff and total precipitation has an R^2 value of 0.74, while the relationship between total runoff and winter precipitation has an R^2 value of 0.84. The relationship between total runoff and summer precipitation has an R^2 value of 0.15.

The fact that winter precipitation has the "strongest relationship" to total yearly runoff is due likely to the high amount of winter precipitation and less water lost to evapotranspiration (ET). Summer runoff is controlled by the high ET demands during those months and the consequent high soil-recharge demands. During the summer there is a "weak correlation" between runoff and precipitation (R^2 = 0.03). In the winter months, the coefficient of determination between precipitation and runoff was highly significant (R^2 = 0.86). This same pattern has been shown in other mixed conifer forests. For example, Franco-Vizcaino et al. (2002) analysis of worldwide streamflow and ET values showed that as watershed-systems become more water stressed, such as the case in summer months, the positive relationship between ET and precipitation increases while the correlation of precipitation and streamflow decreases.

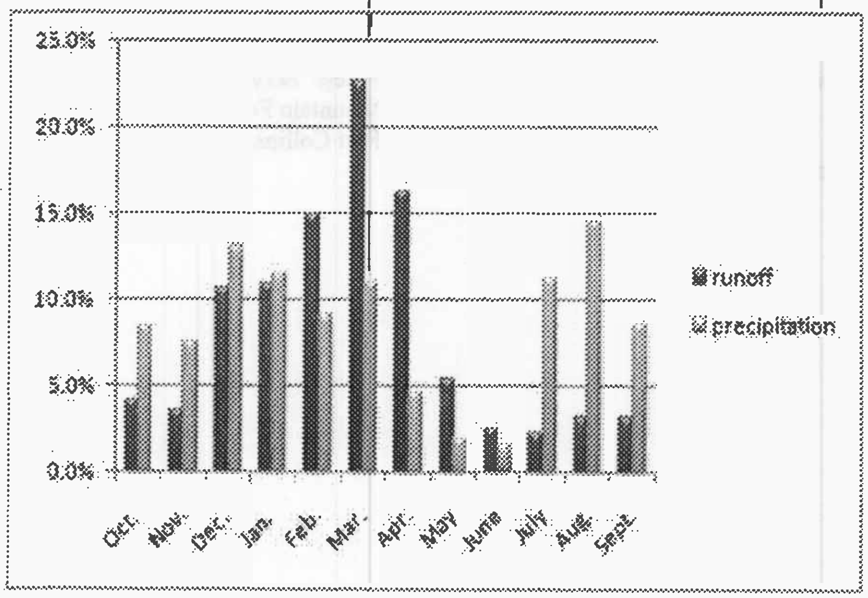

Figure 2. Comparison of average monthly precipitation and runoff at Workman Creek. Data are presented as monthly percents of total of the annual precipitation and runoff to illustrate the trend therein. Due to the location of the precipitation gauge at a lower elevation, the actual quantities of precipitation are not included. Runoff in winter months is related more to snowmelt than to precipitation received during that month.

CONCLUSIONS

This analysis of Workman Creek was made possible because of the many years that Rocky Mountain Research Station personnel spent working at Workman Creek, and, therefore, it underscores the necessity for long-term research projects. To understand long-term trends, a commitment must be made to long-term research. Without long-term records, information of the possible effects of climate change is impossible. The 20-year gap in the records at Workman Creek was unfortunate. However, a "representative record" for this watershed is being obtained through the data-analysis presented in this paper and the data currently being collected on the watershed. Not only are streamflow-measurements continuing, but air-pollution monitoring equipment is being installed on the Sierra Ancha Experimental Forest to further increase our knowledge of the climate of this mid- elevation watershed.

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