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

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Water is a vital natural resource, and in the Southwest its paucity makes it of particular importance. There is a long history in the Southwest of research on increasing water yield 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 stormflow and sediment yields after it was discovered that 101,000 ac-ft of sediment had accumulated behind Roosevelt Dam (Gottfried et al. 1999). Watershed studies on Workman Creek were initiated in 1938 to investigate the hydrology of mixed conifer forests and determine the effects of manipulating mixed conifer forests to increase water yield. Streamflow was monitored from 1939 to 1980 at the four gaging stations.

Three watersheds, North Fork, Middle 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 silvicultural treatments on North Fork was to determine the water yield increase possible from converting a mixed conifer forest into grassland in stages. The objective of the treatments on South Fork was to determine hydrologic effect of the current management practices. Middle Fork was the control. The watersheds were calibrated 13 years prior to treatment.

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SITE DESCRIPTION

The Workman Creek watershed is located in Central Arizona approximately 30 mi north of Globe in the Sierra Ancha Experimental Forest. The climate at the study site has two wet seasons, winter which receives approximately 67% of precipitation and summer which receives approximately 33% of annual precipitation. Precipitation measured on Middle Fork from 1938 through 1973 averaged 32.89 in. Winter (October-May) averaged 22.01 in, and summer (June-September) averaged 10.88 in (Rich and Gottfried 1976). The elevation ranges from 6590 to 7724 ft. The basin drains to the west, and is divided into three catchments ranging in size from 248 to 521 ac, 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 ft. The soils rest on Dripping Springs quartzite with intrusions of diabase, and basalt plugs and sills (Rich et al. 1961).

The pre-treatment forest was mixed conifer with ponderosa pine (*Pinus ponderosa*) being the most common tree, especially on the drier sites. On the wetter sites, Douglas fir (*Pseudotsuga menziesii*) and white fir (*Abies concolor*) become more common. The understory 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*). See table 1 for proportions of trees on the three watersheds. There was a 20 acre meadow on Middle Fork and a 2 acre meadow on South Fork. Other than those two meadows, grass and herbaceous cover was less than 1% of the ground surface (Rich et al. 1961).

Table 1. Percent of overstory of dominant species on the three sub-watersheds at Workman Creek prior to treatment application (from Rich et al. 1961).

Watershed	Total area (acres)	Ponderosa pine	White fir	Douglas fir	Gambel oak	Other	Basal area (ft^2/acre)
		Average tree compostion					
North Fork	248	52.2%	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

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 conifer forests by changing the cover type to grass. The trees were removed in a series of steps addressing the riparian vegetation, mixed conifer component, and ponderosa pine component respectively.

The first treatment removed riparian trees, mainly Arizona alder and bigtooth maple from around the streams, seeps, and springs. After the trees were cut, the stumps were coated with herbicides to prevent sprouting, a common regeneration strategy for these species. The riparian cut removed 0.6% of the total basal area of North Fork with no statistically significant increase in water yield compared to the control watershed. The cut did, however, increase summer stormflows and peaks in the 5 year period following the cut by up 280% for rainfall events larger than 2 in (Hibbert and Gottfried 1987).

The second treatment on North Fork converted the moist site mixed conifer forest, predominantly Douglas fir and white fir, to grass. About 80 ac, approximately 32% of the watershed, was clear cut in 1958. The treatment resulted in water yield increases of 42% or 1.26

in for average conditions (Rich and Gottfried 1976). Increases of 322 to 442% were observed for summer stormflows and peaks for storms of 1 to 2 in. Modest increases in stormflow of approximately 30% were reported for winter storms. The percent increases were smaller for winter storms than summer storms, but had a larger volume increase in water yield (Hibbert and Gottfried 1987).

The third treatment on North Fork converted the 100 ac dry site, predominantly ponderosa pine, although Douglas fir and white fir were also represented, to grass. In the fall of 1966, the timber harvest of about 100 ac was completed. During the winter of 1969 a prescribed fire removed much of the remaining stand. Any surviving trees were treated with herbicide, completely clearing the stand. This treatment increased water yield 1.32 in (Rich and Gottfried 1976). Summer stormflows and peaks were overall similar to moist site treatment (Hibbert and Gottfried 1987).

The combined effect of the treatments was an increase of 2.7 in or 84% (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 will be discussed here.

The first treatment, a single tree selection, on the South Fork started in June 1953 and ended in November 1955, reducing the basal area 24%. 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 a 60 ft buffer around the stand. As well

as infested pine, 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%. A wildfire in 1957 burned the 60 ac on the southeast section of the watershed, removing another 9% of the total basal area. Other damage associated with logging (i.e. access roads and skid trails) reduced the basal area 6%. All told, basal area was reduced 45%. This treatment did not significantly increase water yields (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. Stormflow peaks increased 5 to 10 times. 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 the treatment, basal area on the watershed was 118 ft^2 /ac. Merchantable timber was removed from the watershed and the remaining trees were thinned to a density of 40 ft^2 /ac. Areas infested with dwarf mistletoe and areas of fir were cleared, then windrowed and burned. About 55 ac of thinned pine remained, with the rest of the watershed mostly cleared. Reforestation efforts were largely frustrated by plant competition and 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 in storms of less than 1.5 in, in which case the responses were about equal. A minor increase in winter stormflows and peaks were attributed to this treatment (Hibbert and Gottfried 1987).

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

Table 2. Treatment types and application dates on the North Fork and South Fork watersheds of Workman Creek as reported by 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%

In 1980 the weirs were shut down due to USDA Forest Service shifting priorities (Gottfried et al. 1999). In 2000 the weirs were reactivated after the Coon Creek Fire, a 9,644 ac fire burned the three watersheds (Gottfried et al. 2003). This paper will analyze the patterns and trends in flow measured at the Main Dam from 1939 to 1980.

METHODS

Workman Creek streamflow data were collected from archived files at the Rocky Mountain Research Station Flagstaff Lab. Each water year has a complete file of daily and monthly summaries. For the purposes of this paper and to make the Sierra Experimental Forest

legacy data widely available (via RMRS website[3]) 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 flow were calculated for a given water year. A water year is from October 1st thru September 31st and named for the year in which it ends (e.g. WY 1939 is from October 1st 1938, thru September 31st 1939). Winter flows are between October 1st and May 31st, while summer flows are between June 1st and September 31st of a given water year.

Precipitation data were gathered from the Western Regional Climate Center. The rain gauge data were collected from a site that is approximately 3 mi from Main Dam, but is about1400ft lower in elevation. Though there is a large discrepancy in elevation this was the closest gauging station with long term records to use in this analysis in determining trends in streamflow at Workman Creek.

RESULTS AND DISCUSSION

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

[3] Rocky Mountain Research Station Southwest Watershed Team webpage—links to legacy data summarized thus far, will be up-dated as digitization and summaries are completed: http://www.rmrs.nau.edu/awa/sierraancha.

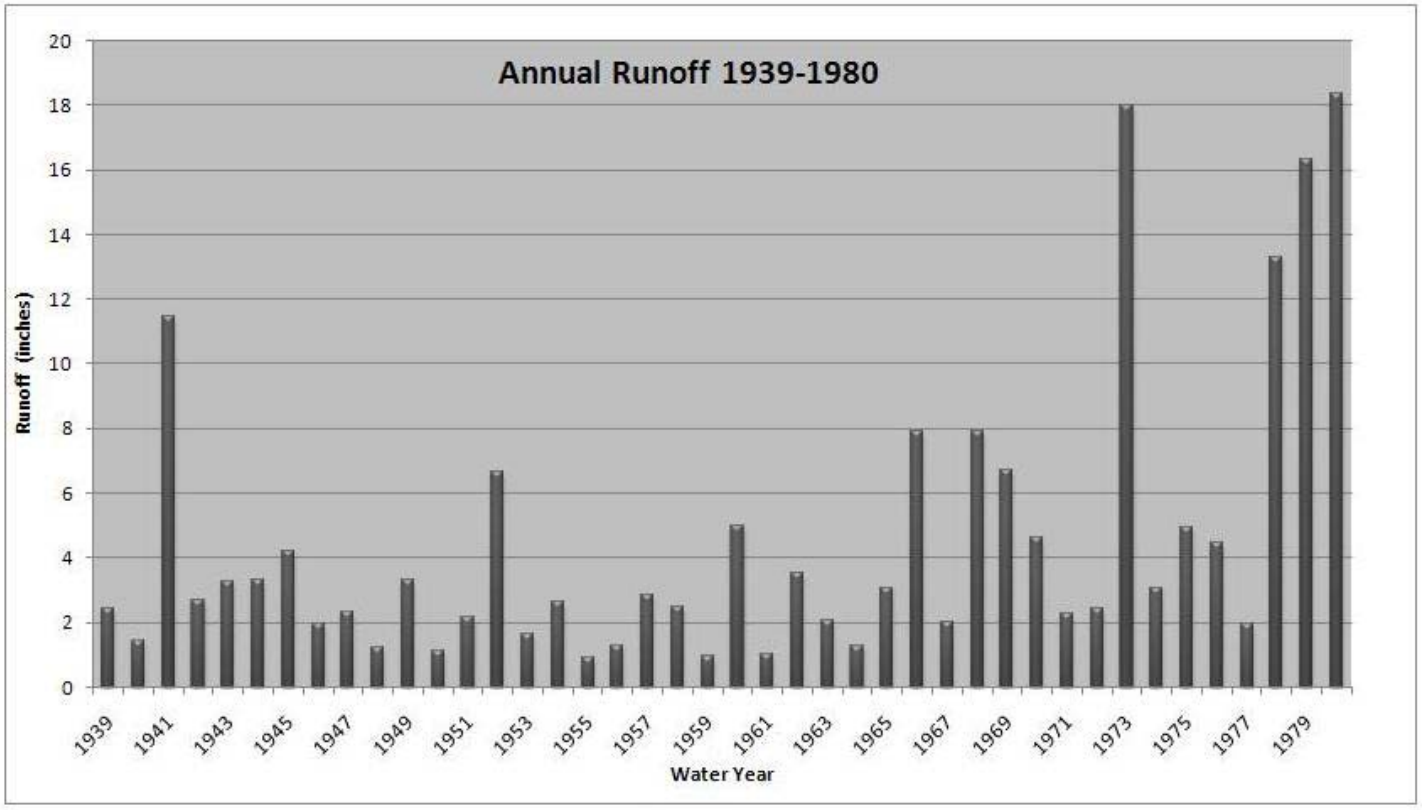

Figure 1. Total yearly runoff at Main Dam of Workman Creek from 1939-1980.

Due to the bimodal precipitation pattern of this region, the data were lumped into winter runoff and summer runoff. Winter runoff is calculated as all runoff from October through May, and summer is June through September. Winter runoff accounted for 89% of total runoff, and winter precipitation accounted for 66% of total yearly precipitation. Summer runoff was 11% of total yearly runoff, and summer precipitation was 33% of total yearly precipitation. These data illustrate that winter precipitation is the primary driver of runoff. The relationship between total runoff and total precipitation has an R^2 of 0.74 where as the relationship between total runoff and winter precipitation has an R^2 of 0.84. The relationship between total runoff and summer precipitation has an R^2 of 0.15. The winter precipitation having the strongest relationship to total yearly runoff is due to the high evapotranspiration demands during the summer months. During

the summer there is a weak correlation between runoff and precipitation (R^2 = 0.03). In the winter months, the correlation between precipitation and runoff is strong (R^2 = 0.86. This same pattern has been shown to be the case in other mixed conifer forests. The Franco-Vizcaino et al. (2002) analysis of worldwide streamflow and ET data show that as systems become more water stressed, such is in the summer months, the positive relationship between ET and precipitation increases while the correlation of precipitation and streamflow decreases.

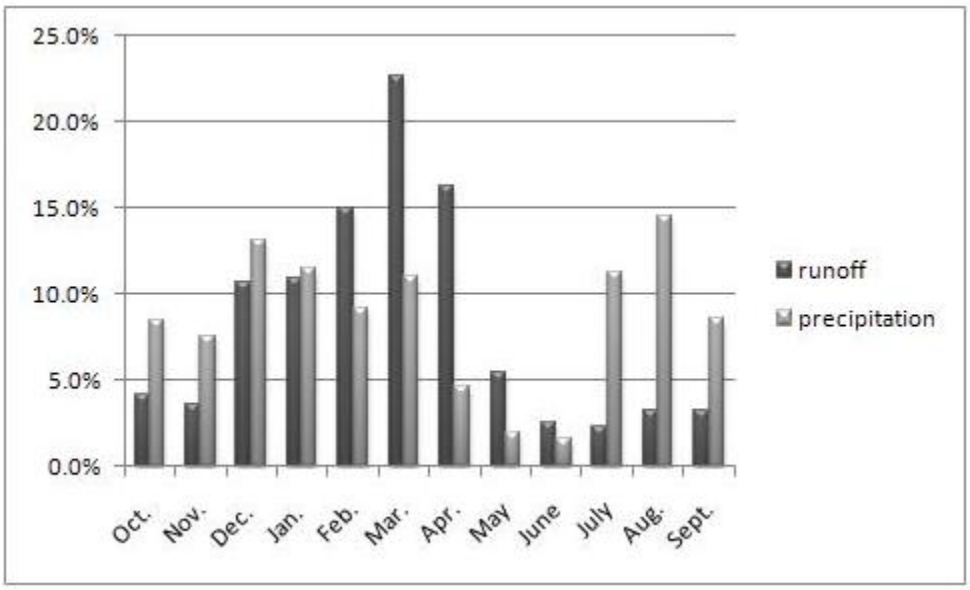

Figure 2. Comparison of average monthly precipitation and runoff at Workman Creek. Data are presented as monthly percents of total of the annual precipitation and runoff to illustrate the trend therein. Due to the location of the precipitation gauge at a lower elevation, the actual quantities of precipitation are not included.

CONCLUSION

This analysis of Workman Creek was only possible because of the many years Rocky Mountain Research Station personnel spent working at Workman Creek. 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 understanding effects of climate change is impossible. The records at Workman Creek break at 1980 and are not resumed again until 2000. This 20 year gap is unfortunate, but with the data discussed in this paper and the current data being collected there is an impressive record of this watershed. Not only has the runoff monitoring continued, but new air pollution monitoring equipment is being added to the Sierra Ancha Experimental Forest to further increase our knowledge of this high elevation watershed.

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