HYDROLOGY OF THE UPPER PARKER CREEK WATERSHED, SIERRA ANCHA MOUNTAINS, ARIZONA

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The hydrology of headwater watersheds and river basins is variable because of fluctuations in climate and in watershed conditions due to natural or human influences. The climate in the southwestern United States is variable, with cycles of extended periods of drought or of abundant moisture. These cycles have been documented for hundreds of years in the tree rings of the Southwest (Swetnam and Betancourt 1998). Hydrologic records that only span a decade or so may not provide a true indication of watershed responses because the measurements could be from a period of extreme climatic conditions. This inherent variability dictates that the best understanding of hydrologic responses must be based on long-term records. Land and water managers, who are charged with predicting the impacts of land management activities, are hindered by the lack of long-term hydrologic information. However, some relatively long-term records exist throughout the United States because of the watershed research programs that were initiated by the USDA Forest Service and other state and federal agencies. Some of the records have never been updated or completely analyzed.

The hydrologic records from the Upper Parker Creek watershed in the southern part of the Sierra Ancha Mountain Range in central Arizona have not been fully analyzed. However Ward (1995) did include the watershed in his studies of channel morphology of streams within the Sierra Ancha Experimental Forest (Figure 1). The watershed has been monitored intermittently since the summer of 1934. The current record includes 54 complete years of runoff data and an additional 2 years with primarily summer data, as well as 25 years of precipitation records. This paper collates and summarizes the existing record, examines some of the hydrologic relationships within the Upper Parker Creek watershed, and reevaluates the hypothesis that Upper Parker Creek could serve as the hydrologic control for post-fire streamflow evaluations being conducted on the nearby Middle Fork of Workman Creek, which burned in 2000. The present knowledge of wildfire effects on hydrologic responses is low, and data from Upper Parker Creek and Workman Creek should help alleviate the gap. The relationships for annual and seasonal runoff volumes are of particular interest in the present evaluation; subsequent analyses will evaluate relationships for peak flows.

HISTORY

The Upper Parker Creek watershed was one of the first instrumented after the USDA Forest Service, Southwestern Forest and Range Experiment Station established the Parker Creek Experimental Forest in 1932 (Figure 1). The area of the experimental forest was enlarged in 1938, and the name was changed to the Sierra Ancha Experimental Forest. The Parker Creek headquarters is about 40 mi from Globe, Arizona. The experimental forest was located on this site because it encompassed the range of forest and rangeland conditions typical of the Salt River Basin and other Southwest drainages. Elevations range from 2500 to 7700 ft; the vegetation extends from desert shrub to mixed conifer forests (Pase and Johnson 1968). In 1982, the Parker Creek watershed, including the ungauged North Fork, was proposed as a research natural area (RNA), although a final determination still has not been made. The USDA Forest Service's RNA committee for the Southwestern Region was impressed with the riparian vegetation and by the availability of good climatic and hydrologic records. Livestock have not grazed in the Upper Parker Creek watershed since the late 1930s. The Rocky Mountain Research Station currently administers the experimental forest, which is located within the Tonto National Forest.

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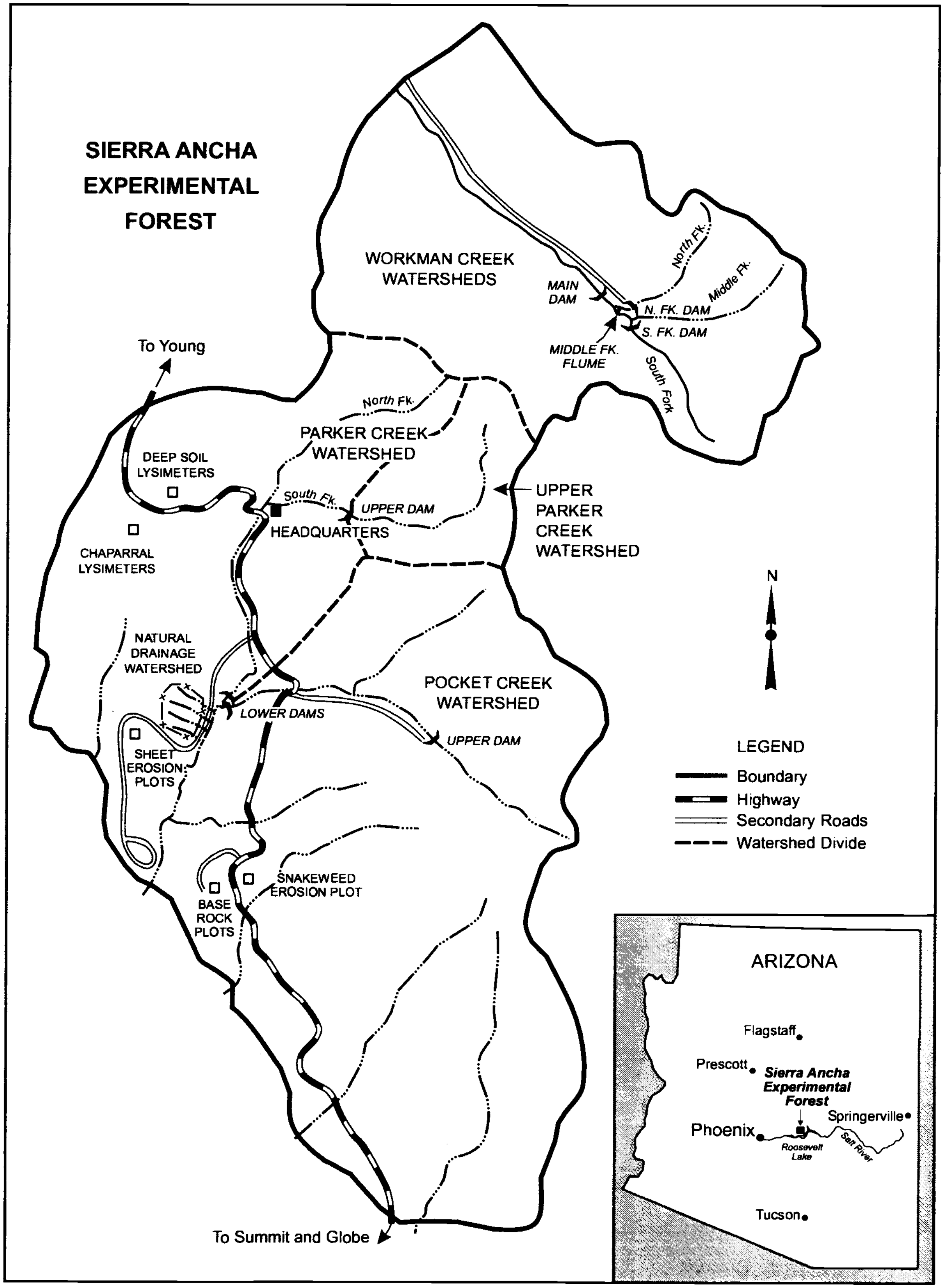

Figure 1. Map of the experimental watersheds and main study sites on the Sierra Ancha Experimental Forest in central Arizona modified from USDA Forest Service (1953). The Lower Parker Creek and two Pocket Creek watersheds were deactivated in October of 1972.

The Upper Parker Creek watershed was instrumented with a 90° V-notch weir and an 8 ft Cipoletti weir, and measurements began in June of 1934 (Figure 1). Records were collected continuously through the 1972 water year. Annual runoff is based on a water year that includes the period between October 1 and the following September 30. Cooperrider et al. (1945) used Parker Creek data to develop a fairly accurate method of forecasting March through May runoff from the Salt River above Roosevelt Dam. The intense storms of October 1972 caused the settling basin for the installation to fill up with relatively large boulders and cobbles. The costs to clean the structure and the lack of anticipated experimental studies resulted in a decision to close the weirs. No vegetation manipulation treatments were ever applied to the watershed.

The weirs and basin were cleaned and reopened in 1977 in anticipation of Upper Parker Creek serving as the hydrological control for a planned experimental timber harvest on the Middle Fork of Workman Creek, which is located within the experimental forest and northeast of Parker Creek (Figure 1). Middle Fork had served as the hydrologic control during earlier watershed experiments on the North Fork and the South Fork of Workman Creek that involved several timber harvesting or vegetation manipulation prescriptions (Gottfried and Neary 2001; Hibbert and Gottfried 1987; Rich and Gottfried 1976). The Workman Creek watersheds were instrumented in 1939, and experimental treatments were begun in 1953. South Fork was treated with a single-tree selection harvest at that time and in 1966 by a treatment designed to convert the watershed to a ponderosa pine (*Pinus ponderosa*) cover with a stand density of 40 ft^2/ac. The experimental treatments on North Fork were designed to evaluate the progressive removal of forest vegetation and conversion to grass cover on streamflow volumes. The first treatment in 1953 (USDA Forest Service 1953) removed the riparian trees, the second in 1958 removed the mixed conifer forest cover from 80 ac on moist sites adjacent to the stream channels, and the last treatment in 1966 removed the commercial ponderosa pine cover from 100 ac on drier sites.

Runoff from the 521 ac Middle Fork of Workman Creek is determined by subtracting flows from South Fork and North Fork from those at the main dam, which is located on the main stem of Workman Creek below the confluence of the three forks and measures the entire 1087 ac area (Hibbert and Gottfried 1987), and at a trapezoidal flume that measures the main 411 ac unit of Middle Fork. An analysis of the quadratic regression model of annual runoff indicated that Middle Fork (as determined at the main dam) and Upper Parker Creek were related, with a coefficient of determination (r^2) of 0.91 (Gottfried 1977). A strong statistical relationship also existed between annual flows at the Middle Fork flume and Upper Parker Creek ($r^2 = 0.92$). The planned treatment was never applied to Middle Fork.

Significant relationships were also estimated between annual flows in Upper Parker Creek and those in the North and South Forks of Workman Creek for the various treatment periods since 1939 (Gottfried 1977). Streamflow was measured through the 1983 water year, when most watershed studies throughout the Southwest were terminated in a program redirection.

The three Workman Creek watersheds burned in the Coon Creek Wildfire of April-May 2000, and these installations, which also were closed in 1983, were reopened by the Rocky Mountain Research Station and the Tonto National Forest to measure the impacts of this wildfire on peak flows, runoff volumes, and erosion and sedimentation. Middle Fork, with its dense, old-growth stands of mixed conifer and ponderosa pine trees, suffered high burn intensities; the other two watersheds burned at low or moderate intensities (Gottfried and Neary 2001). The Upper Parker Creek watershed is being evaluated as the hydrologic control for postfire studies at Workman Creek.

The U.S. Geological Survey (USGS) took responsibility for the Upper Parker Creek installation in 1985. Except for a break from October 1992 through May 1994, the USGS has maintained the records to date.

WATERSHED CHARACTERISTICS

The Upper Parker Creek weirs measure intermittent streamflow from a 700 ac watershed within the South Fork of Parker Creek (Figure 1). The installation is located at 5440 ft and 1.5 mi above the confluence of Parker and Pocket Creeks. The upper boundary of the watershed is over 7400 ft in elevation. Initially, the stream flows to the south from its origin but curves to the west for most of its course through the experimental forest. Most of the watershed contains steep slopes and cliffs, except near the top, where areas with 10 percent slopes occur. The channel length above the weirs is about 9800 ft and the slope is 17.4 percent (Ward 1995). Bedrock and boulders control the channel characteristics; fluvial deposits occur where boulders or organic debris have formed dams and subsequent step-pool sequences (Ward 1995).

The mean annual precipitation at the weirs for the 25 years of record between 1948 and 1972 was 23.70 ± 1.05 inches (mean with standard error), with about 63 percent occurring during the winter months. A 66 yr precipitation record at the Sierra Ancha weather station in the headquarters complex (Figure 1), approximately 1 mi below the weirs and located at 5100 ft in elevation, indicates mean annual precipitation of 25.62 ± 0.95 inches, with 68 percent occurring in winter. The station is within the Parker Creek Basin. Records from the weather station in the Middle Fork of Workman Creek, at an elevation of about 6900 ft (Figure 1), indicate an annual mean precipitation of 32.8 ± 1.5 inches from 1939 through 1981 (Hibbert and Gottfried 1987), mostly as snow. The Middle Fork station should approximate conditions in the headwaters of Parker Creek. Winter storms generally are frontal storms originating from the Pacific Ocean, whereas summer rains occur as convectional storms derived from monsoon moisture coming from the Gulf of Mexico.

The primary vegetation is ponderosa pine or mixed conifer forests, containing ponderosa pine, Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), white fir (*Abies concolor*), alligator juniper (*Juniperus deppeana*), and oaks (*Quercus* spp.). Some large old alligator juniper trees exhibit fire scars that were probably caused by lightning. Chaparral predominates on the south-facing slopes. The chaparral at upper elevations consists of tree oaks and several shrub species such as shrub live oak (*Quercus turbinella*), true mountain mahogany (*Cercocarpus montanus*), and Pringle manzanita (*Arctostaphylos pringlei*). The riparian zone consists of Arizona alder (*Alnus oblongifolia*), bigtooth maple (*Acer grandidentatum*), and Arizona walnut (*Juglans major*).

The Sierra Ancha Mountains are geologically within the Transition Zone Province that lies between the Colorado Plateau and the Basin and Range Provinces (Nations and Stump 1996). The main geologic formation in Parker Creek is Dripping Springs Quartzite and Barnes Conglomerate, which is its basal member. Intrusions of basalt and diabase dikes and sills occur throughout the formation. The quartzite is part of the Apache Group that formed during the Middle Proterozoic Era, about 1600 to 900 million years ago, and is common in the mountains surrounding the Tonto Basin and in parts of southeastern Arizona (Nations and Stump 1996). The resistance to weathering of this formation results in generally shallow fine-textured soils that have limited water penetration and storage capacity. The high water yields from Parker and Pocket Creeks have been linked to these soil characteristics (Pase and Johnson 1968). The soil horizons are poorly defined and usually contain a large amount of disintegrated quartzite rock. Soil losses during summer rain events after severe fires can be high in these canyons. Hendricks and Johnson (1944) recorded losses equivalent to between 32 and 165 tons/ac after a fire on steep slopes in the adjacent Upper Pocket Creek watershed (Figure 1).

METHODS

The objective of this study was to evaluate the long-term hydrology of the Upper Parker Creek watershed and to reevaluate the possibility of using Upper Parker Creek data to evaluate the effects of the Coon Creek Fire on runoff from the Middle Fork of Workman Creek. The present analyses are an initial evaluation of the Upper Parker Creek and Workman Creek records. Data on file at the Rocky Mountain Research Station in Flagstaff, Arizona provide the main basis for the effort. The Upper Parker Creek record includes streamflow volume and peak flow data for 1934–1972 and 1977–1980. The record includes 42 complete water years and 1 partial year (1934). Our analyses included monthly, winter, summer, and annual streamflow. The winter period consists of October through May. The peak winter and summer flows for each year were determined.

The Rocky Mountain Research Station also has 25 years of precipitation data for Upper Parker Creek for 1948–1972. These runoff and precipitation data were compared to the 66 yr record at the Sierra Ancha Station to determine if the longer record can be used to extrapolate records for Parker Creek. A weather station was also established in the Middle Fork of Workman Creek in 1939 and was maintained through 1983; it was reestablished after the Coon Creek Fire.

The USGS record is derived from its Web page (http://water.usgs.gov/az/nwis) and from its annual publications (e.g. Tadayon et al. 1998). The watershed is listed as USGS 09498503: "South Fork Parker Cr. Nr. Roosevelt AZ." The record includes information needed to calculate monthly streamflow volumes for 12 full years and 1 partial year (1986). Several years with only 1 or 2 months of record were not included. The peak flow for a year appears on the USGS Web site, but only one value is presented instead of both winter and summer values.

The analyses included evaluations of the means for the available record. The power regression model, usually with the curve forced through zero, was used to describe the relationship between precipitation and annual runoff and between runoff from the Upper Parker Creek and the Middle Fork of Workman Creek flume and Upper Parker Creek and the calculated Middle Fork values. Linear, quadratic, and standard power regression models were also evaluated. Means are presented with standard errors and significance is indicated by $\alpha = 0.05$.

RESULTS AND DISCUSSION

Annual and Seasonal Runoff

The mean annual runoff for the 54 years of complete record at Upper Parker Creek is 5.66 ± 0.65 inches. The greatest runoff occurred in 1941 when 20.89 inches were measured (Figure 2), a record year throughout the Salt River Basin. The Sierra Ancha precipitation for the year was 45.24 inches, with 85 percent occurring in the winter. Runoff at the Middle Fork of Workman Creek that year was 13.22 inches, derived from 52.86 inches of precipitation. Some 88 percent of the precipitation at the higher elevation occurred during the winter, mainly from December through April. The average annual runoff from Middle Fork between 1939 and 1979 was 3.29 ± 0.60 inches. A significant linear regression (adjusted $r^2 = 0.90$) can be used to estimate precipitation for Upper Parker from the Sierra Ancha Station data, but the 1941 value exceeds the upper range of the data used to construct the relationship. If we assume that the 45 inches of precipitation is close to the true value for 1941, then the Upper Parker Creek watershed had an efficiency (proportion of runoff to precipitation) of 46 percent, whereas Workman Creek had an efficiency of only 25 percent. The difference between the two catchments for 1941 and for the long-term mean runoff can be related to physiography and soil characteristics. Upper Parker Creek has vertical cliffs and steep slopes with shallow soils, and Workman Creek, which supports a perennial stream, is relatively level with deep soils with high water-holding capacity. Some soils are more than 15 ft deep (Rich and Gottfried 1976). The greatest recorded precipitation in the southern Sierra Ancha Mountains occurred in 1973 when 45.79 inches were recorded at Sierra Ancha and 60.92 inches were recorded at Workman Creek; however, Upper Parker Creek was not in operation that year. The lowest runoff year was 1996 when 0.18 inch was measured at the Parker Creek weirs. The Sierra Ancha Station recorded 14.17 inches of precipitation that year; only 38 percent fell in the winter. There have been years with less precipitation, but most fell during the winter when soils were recharged and water movement was more efficient. Antecedent soil water also influences runoff; precipitation on a recharged watershed will yield more runoff for the same amount of water on a dry watershed.

Winter runoff at the Upper Parker Creek weirs has averaged 5.35 ± 0.66 inches, or 95 percent of the annual total, and summer runoff has averaged 0.30 ± 0.10 inches. The highest winter flows occurred in 1941 with 20.47 inches, and the highest summer flows were in 1951 with 4.25 inches. The Parker Creek gauge recorded 14.74 inches of precipitation that summer. The smallest winter flow of 0.16 inch occurred in 1996, and there were five summers (1948, 1950, 1961, 1972, and 1997) when no runoff was measured.

Monthly Runoff

March has the highest monthly runoff with a value of 1.75 ± 0.23 inches, followed by February with 1.27 ± 0.22 inches (Figure 3). July, June, and October had the lowest mean streamflow. No flows were measured in July during 30 of 56 years, or 54 percent of the total record. Periods without flows have also occurred in November, August, and September. The highest monthly flow of 8.19 inches was in February of 1980, and the second highest was 7.01 inches in March of 1978. Both high runoff quantities occurred during periods when the Salt River flooded parts of the Phoenix metropolitan area. The Sierra Ancha station records show that these runoff periods occurred in wet months that followed even wetter months. In 1980, January received 11.55 inches followed by 7.13 inches and in 1978, February received 10.95 inches followed by 9.95 inches.

Precipitation and Runoff

Only 25 years have a common annual precipitation and runoff record from the Upper Parker Creek installation. Average annual precipitation was 23.70 ± 1.05 in, with 63 percent occurring during the winter. A power regression relationship developed for the annual data (Figure 4, Table 1)

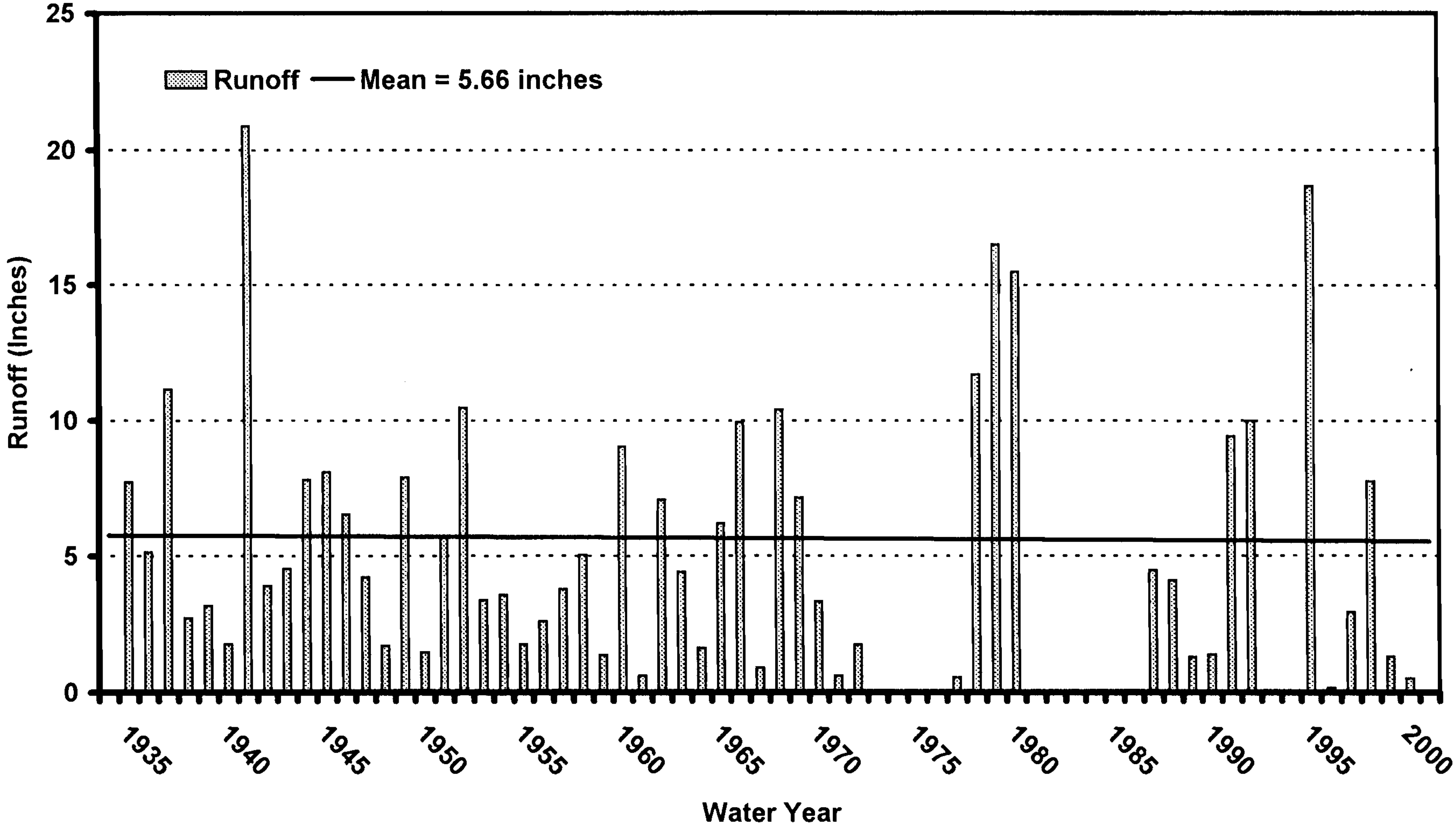

Figure 2. Runoff in inches for the Upper Parker Creek watershed for the 54 water years with complete records from 1935 through 2000. There are three periods since 1972 when the weirs were not in operation. Data from 1935–1980 are from the Rocky Mountain Research Station and from 1985–2000 are from the U.S. Geological Survey.

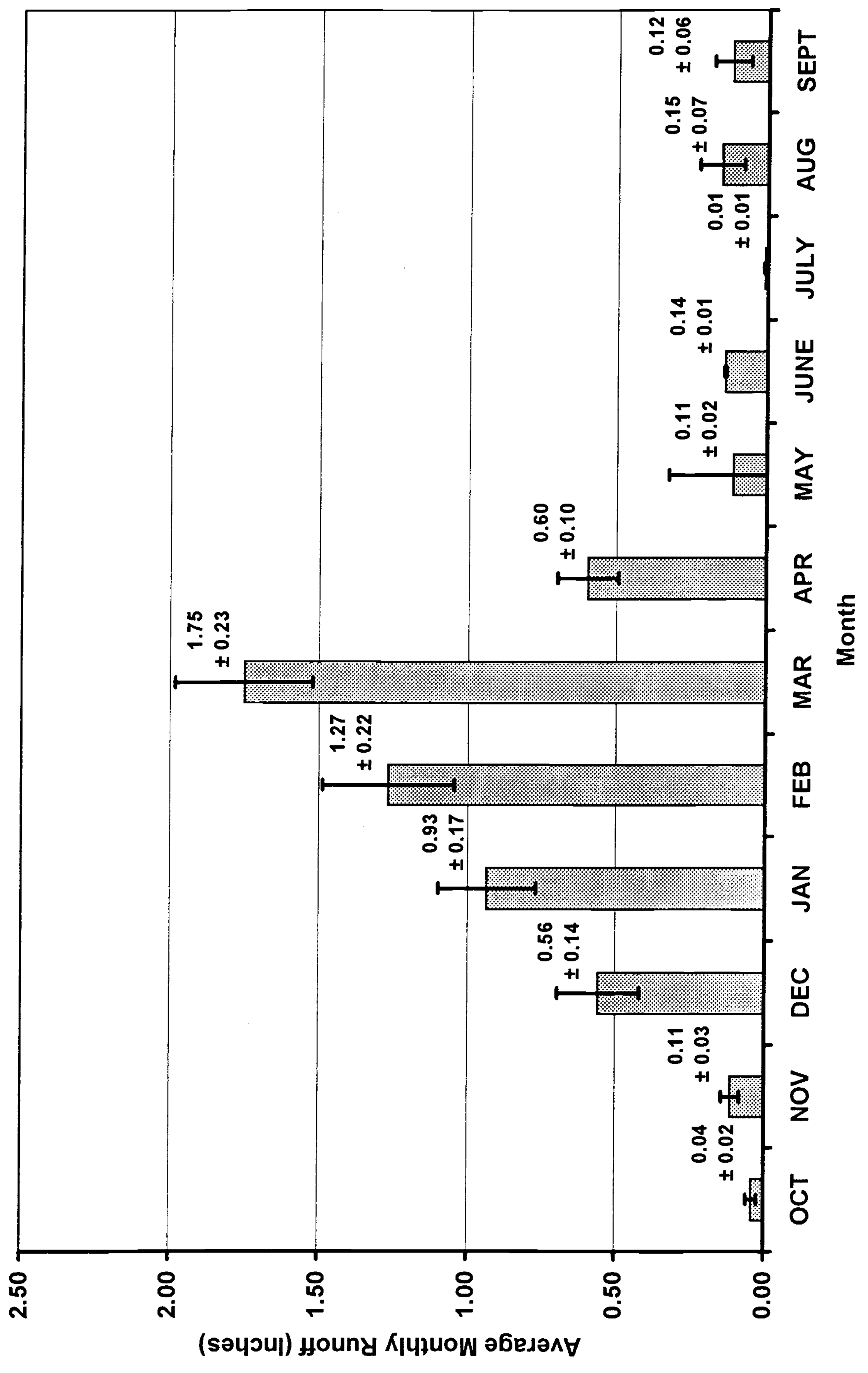

Figure 3. Average monthly runoff (with standard errors) for Upper Parker Creek for the record between 1934 and 2000.

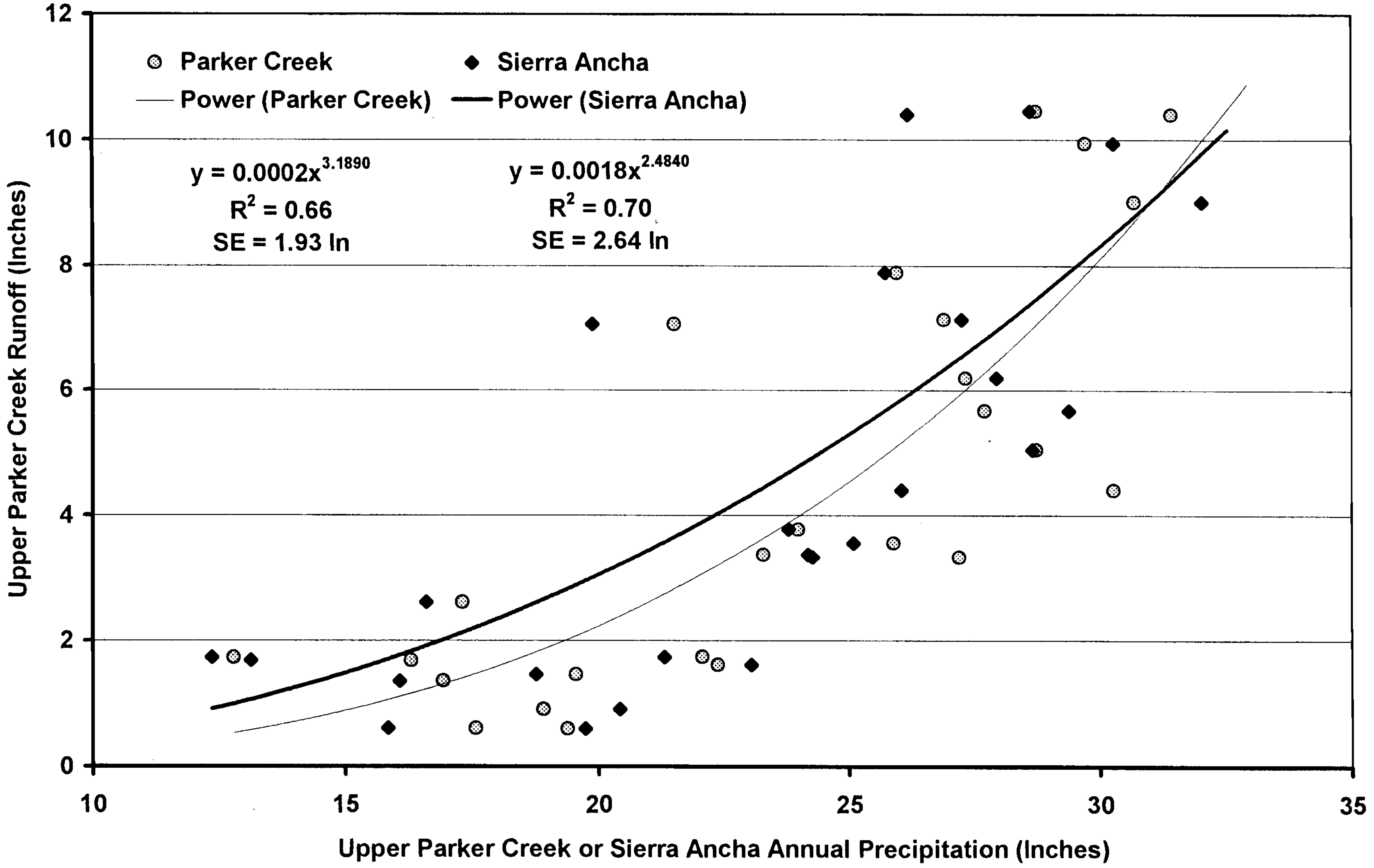

Figure 4. The relationships between annual precipitation at Upper Parker Creek and at Sierra Ancha and Upper Parker Creek annual runoff. Annual runoff and precipitation are based on the water year that includes the period from October 1 through the following September 30.

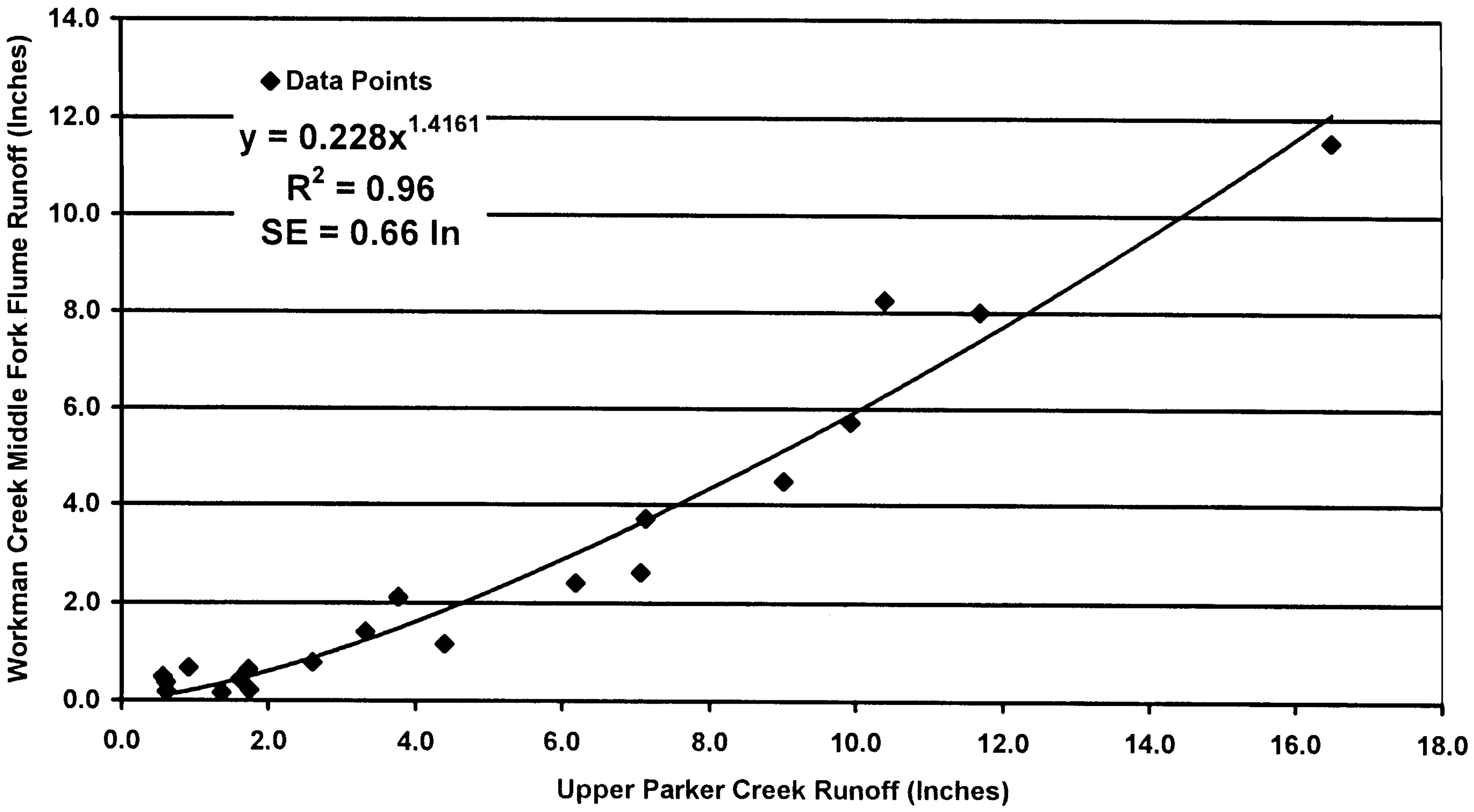

Figure 5. Relationship between annual runoff from the Workman Creek Middle Fork flume and Upper Parker Creek for the record between 1955 and 1979.

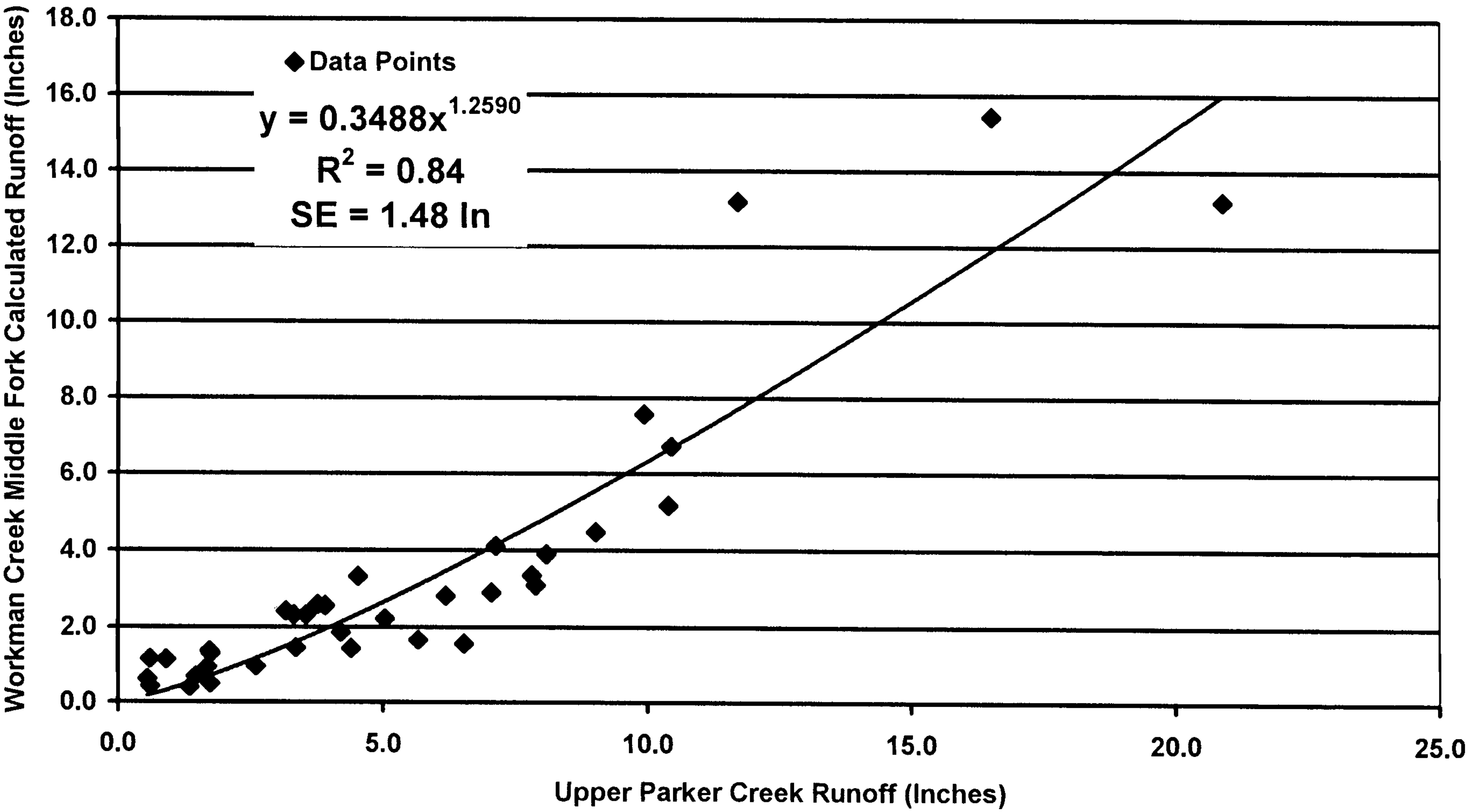

Figure 6. Relationship between annual runoff for the Workman Creek Middle Fork calculated from the main dam records and Upper Parker Creek between 1939 and 1979.

Table 1. Runoff relationships between the Upper Parker Creek watershed and precipitation measured at the Parker Creek or Sierra Ancha stations.

Precipitation – Runoff

Upper Parker Creek Weir and Precipitation Gauge

Annual Runoff = 0.0002 (Annual Precipitation) $^{3.1890}$, $r^2 = 0.66$, SE = 1.93 inches
Winter Runoff = 0.0014 (Winter Precipitation) $^{2.8624}$, $r^2 = 0.94$, SE = 0.88 inches
Summer Runoff = 0.000004 (Summer Precipitation) $^{4.8730}$, $r^2 = 0.57$, SE = 0.64 inches

Upper Parker Creek Weir and Sierra Ancha Precipitation Gauge

Annual Runoff = 0.0018 (Annual Precipitation) $^{2.4840}$, $r^2 = 0.70$, SE = 2.64 inches
Winter Runoff = 0.0408 (Winter Precipitation) $^{1.7190}$, $r^2 = 0.85$, SE = 1.90 inches
Summer Runoff = 0.00005 (Summer Precipitation) $^{3.8162}$, $r^2 = 0.62$, SE = 0.47 inches

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and for winter and summer data (Table 1) can be used to understand the precipitation-runoff relationship of the watershed.

The longer Sierra Ancha Station record may be more useful than the Upper Parker Creek data. A relationship has been estimated between annual precipitation records for both gauges for the period of common record. The linear regression has an $r^2 = 0.90$. A relationship was also estimated between the Sierra Ancha precipitation and Upper Parker Creek runoff (Figure 4, Table 1). As with the Parker Creek precipitation analysis, the winter regression explained more of the variability than either the annual or summer relationships. The relative strength of the winter compared to the summer relationships can be linked to the general nature of winter storms compared to the cellular convectional summer storms that may not impact the entire watershed or be recorded on all gauges.

Peak Flows

The average winter peak flow was 40.92 ± 7.05 cubic feet per second (cfs), and the highest peak of record of 270.35 cfs occurred on December 23, 1946. The Sierra Ancha station recorded 4.34 inches of precipitation that December, but storm intensities are not readily available. The average summer peak was 12.22 ± 4.96 cfs, and the highest summer seasonal peak was 157.22 cfs on August 19, 1955. More than 13.22 inches of rain fell in July and August, priming the watershed for a high flow event. Significant regressions could not be developed between runoff and peak flows for either season. Ward (1995), who calculated flow duration statistics for days when streamflow occurred at Upper Parker Creek, has indicated that 50 percent of the recorded daily discharges equaled or exceeded 0.1 cfs and that 10 percent were equal to or exceeded 1.5 cfs.

Upper Parker Creek and Middle Fork of Workman Creek

One of the reasons for the interest in Upper Parker Creek is the possible relationship to runoff at Workman Creek, particularly the severely burned Middle Fork. The USGS gauging operation at Upper Parker Creek should ensure high-quality data for the post-fire evaluation period. The Rocky Mountain Research Station and Tonto National Forest reopened the weirs and flume at Workman Creek to measure the hydrologic impacts of the wildfire (Gottfried and Neary 2001). Analyses of 20 years of data show that Upper Parker Creek is a satisfactory hydrologic control for streamflow data from the Middle Fork flume and, based on 37 years of data, for the calculated Middle Fork values from the main dam record. The flume relationship has an $r^2 = 0.96$ (Figure 5) and the calculated Middle Fork relationship has an $r^2 = 0.84$ (Figure 6). Significant relationships between Upper Parker Creek and North Fork and South Fork existed through the 1970s (Gottfried 1977); these need to be retested using the current records.

Changes in peak flows after a fire are important because they affect downstream and local flooding and soil and channel erosion and sedimentation. A preliminary analysis was conducted to determine if there was a relationship between instantaneous peak flows at the Upper Parker Creek weirs and the main dam at Workman Creek. Annual peak discharge values, summarized by Ward (1995), were compared for the 35 years of common record for the period 1939–1979. However, only the 18 pairs of peak flows, which occurred within 2 days of each other on both watersheds, were analyzed because they should represent similar precipitation, rain on snow, or snowmelt events. Peak flows measured at the main dam should be used with caution to interpret any changes in peak flows from Middle Fork because they also reflect any changes in streamflow resulting from the control period and treatments on North Fork and South Fork. The average peak flow for the common dates was 57.67 ± 10.81 cfs at Upper Parker Creek and 62.35 ± 16.57 cfs at the main dam. The standard power regression model estimated a significant relationship with an $r^2 = 0.50$ and a standard error of 1.01 cfs. The regression equation is

$$\text{Middle Fork annual peak flow} = 0.3200\ (\text{Upper Parker annual peak flow})^{1.1974}.$$

As with the precipitation-runoff relationships, the winter relationship had a higher coefficient of determination (0.70) and a lower standard error (0.80) than either the annual or summer relationships for peak flows. The relationship is:

$$\text{Middle Fork winter peak flow} = 0.1000\ (\text{Upper Parker winter peak flow})^{1.5841}.$$

The summer relationship, based on only 5 common years, was not significant. Additional analyses of peak flow data from Upper Parker Creek and the Workman Creek stations are planned for the future.

CONCLUSIONS

Long-term records and observations are necessary to understand the biological and physical fluctuations within any ecosystem. Hydrologic records are used to understand dynamic systems and to predict the probability of future events; they increase in value as more information is collected. This need is particularly true in the southwestern United States where extremes in weather are more common than the "average" condition. Records are often scattered, and opportunities for analysis are lost because of changing personnel and agency priorities over time. The current effort is designed to collate more than 54 years of data from the Upper Parker Creek watershed to serve as the basis for beginning to understand the hydrology of these mountain systems and as the basis for future analyses. Several analyses, including estimates of return intervals, can be calculated with greater confidence when based on long-term records. The USGS water resources program has allowed the extension of the historic record. The relationship between Parker Creek and the Salt River runoff into Roosevelt Lake (Cooperrider et al. 1945) could also be revisited and possibly modified because of the longer record and better current computing capabilities.

Hydrologic data from Upper Parker Creek can be used to understand the hydrology of other mountainous watersheds in central and southeastern Arizona where Dripping Springs Quartzite and the Apache Group are important. The present analyses also confirm the earlier work (Gottfried 1977) that the Upper Parker Creek watershed can serve as a hydrologic control for the efforts to monitor fire effects on streamflow and sediment dynamics at Workman Creek. Additional analyses of peak flow data will be conducted to assist with the interpretation of the hydrologic responses to wildfire. Future evaluations will also determine if the 1977 relationships between Upper Parker Creek and the South Fork or North Fork of Workman Creek are still valid.

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