Chapter 2

Beginning of Water Studies in the Central Arizona Highlands

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Introduction

Water has been recognized as an important resource in central Arizona and has affected populations occupying the Salt River Valley for centuries. Water related activities have been documented since about 200 before the common era, when Hohokam Indians settled the Valley and constructed canals to irrigate their fields. Europeans began to settle in the Phoenix area in the late 1860s and depended on irrigation water from the Salt River for agriculture. However, water supplies fluctuated greatly because the river often flooded in winter and dried up in the summer. There were no impoundments to store water for the dry seasons. In 1904, the Salt River Water Users' Association signed an agreement with the United States government under the National Reclamation Act to build a dam on the Salt River below the confluence with Tonto Creek. The Roosevelt Dam, the first of 6 dams on the Salt and Verde Rivers, was completed in 1911.

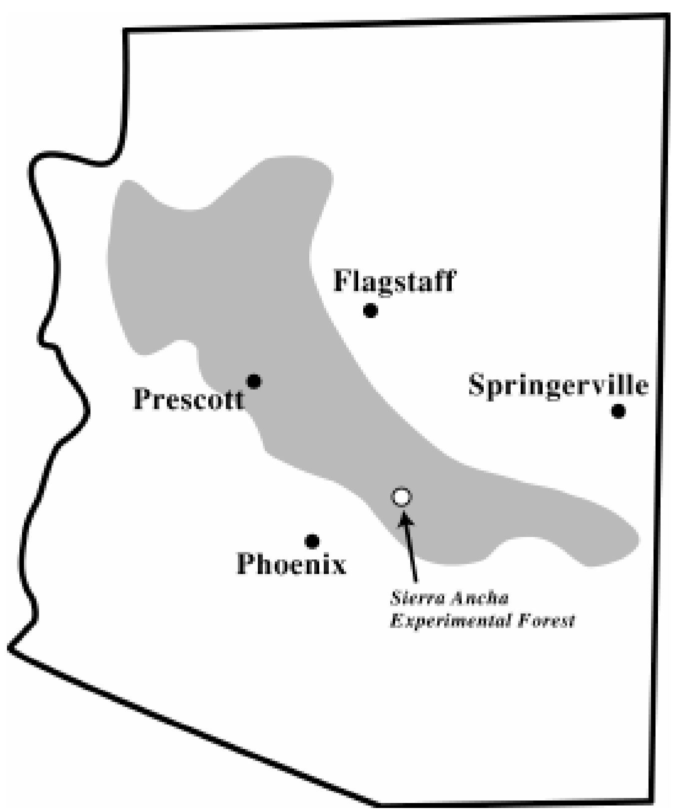

Figure 3. Sierra Ancha Experimental Forest in the Central Arizona Highlands.

In the early 20th century, watershed managers became concerned that erosion on the adjacent and headwater watersheds of the Salt River would move sediment into the newly constructed Roosevelt Reservoir and decrease its capacity. Measurements indicated that 101,000 acre-ft of coarse granitic sediments had accumulated behind Roosevelt Dam between 1909 and 1925. The Summit Plots, located between Globe, Arizona and Lake Roosevelt, were established in 1925 by the USDA Forest Service 15 mi upstream from Roosevelt Dam to study the effects of vegetation recovery, mechanical stabilization, and cover changes on stormflow and sediment yields from the lower chaparral zone (Rich 1961).

Shortly after establishing the Summit Plots, the USDA Forest Service dedicated a research area known as the Parker Creek Experimental Forest in May 1932 (USDA Forest Service 1932). This experimental forest was enlarged and renamed the Sierra Ancha Experimental Forest in April 1938 (figure 3). The hydrologic and ecological experiments that were conducted on the Sierra Ancha Experimental Forest are discussed below.

Other research studies began in the 1950s with establishment of the Three Bar watersheds in chaparral vegetation on the west side of the Tonto Basin (Hibbert et al. 1974, DeBano et al., Chapter 3 of this publication). The initial research objective of the Southwestern Forest and Range Experiment Station (currently the Rocky Mountain Research Station) was to develop a program to study the interrelated influences of climate and soils, topography and geology, and the nature, condition, and use of watershed vegetation on streamflow, soil erosion, floods, and sedimentation.

Sierra Ancha Experimental Forest

The research mission on the Sierra Ancha Experimental Forest was to study the effects of grazed and ungrazed vegetation on water yields and to learn more about water cycle relationships within the diverse vegetation zones extending from the higher elevation mixed conifer forests to the semi-desert grass type (USDA Forest Service 1938). The area of the enlarged experimental forest is about 13,500 acre (USDA Forest Service 1953, Pase and Johnson 1968). The experimental forest is within the Tonto National Forest and is located on the western slope of the Sierra Ancha Mountains about 10 miles from Roosevelt Dam. The hydrologic installations were constructed by the Civilian Conservation Corps during the 1930s.

The experimental forest lies along the crest of the Sierra Ancha Mountain range and includes areas between 3,550 to 7,725 ft in elevation. Geology of the range is complex with sedimentary, metamorphic, and igneous rocks uplifted in a dome-like structure (Pase and Johnson 1968). Thick formations of Dripping Springs quartzite, dissected by deep canyons or with intrusions of diabase and basalt plugs and sills, are common in much of the forest. Troy sandstone occurs at higher elevations (Rich et al. 1961, Pase and Johnson 1968).

Precipitation averages about 33 inches at the higher elevations at Workman Creek, 25 inches at the intermediate elevations (4,800 to 6,000 ft) surrounding the headquarters, and 16 inches at the lower elevations near the Base Rock lysimeters (Pase and Johnson 1968). Pase and Johnson (1968) identified 8 vegetation types including, from high to low elevations: mixed conifer, mountain park, ponderosa pine, chaparral, oak woodland, desert grassland, desert shrub, and riparian. Fifty-seven percent of the experimental forest is covered by chaparral shrubs. The habitat relations of the vertebrate fauna have been described by Reynolds and Johnson (1964).

The Sierra Ancha Experimental Forest provides a unique research environment for conducting short- and long-term studies about basic hydrologic and ecological relationships in vegetation types ranging from mixed conifer forests to lower elevation desert shrub-grassland communities.

Short-Term Studies

Short-term studies were used to investigate hydrological and ecological relationships of different plant communities on the Sierra Ancha Experimental Forest. The results of these studies provided the basis for establishing long-term watershed studies to fully evaluate water-yield responses to brush control in chaparral (Natural Drainages), and to timber harvesting in mixed conifer forests (Workman Creek). Studies were designed to test erosion control and revegetation techniques (Hendricks 1936, 1942, Hendricks and Grabe 1939). Cooperrider and Hendricks (1940) and Hendricks and Johnson (1944) studied the effects of grazing and wildfire on soil erosion. Sykes (1938) and Cooperrider et al. (1945) evaluated winter hydrographs for Parker Creek and the Salt River.

The effect of consumptive use of range vegetation on soil and water resources was determined by using small lysimeters. A lysimeter is an instrument for measuring the amount of water percolating through soils and for determining materials dissolved by the water. Evaporation from bare soil was compared to evapotranspiration from perennial *grasses* and shrubs (Rich 1951).

Fletcher and Rich (1955) developed a method of classifying Southwestern watersheds on the basis of precipitation, potential evapotranspiration, and potential water yields. Most water yields resulted from water stored in the soil during the winter when evapotranspiration is low. High-water yielding areas should be managed for water augmentation, while intermediate and low-water yielding areas should be managed to reduce erosion.

Early ecological studies were concerned with characteristics of the Arizona white and Emory oak trees (Bliss 1937, Pase 1969, Pond 1971). Little (1938, 1939) conducted several botanical studies. The forest floor was recognized as playing an important role providing soil protection, increasing water holding capacity and availability to vegetation, and enhancing plant germination (Hendricks 1941, Pase 1972, Garcia and Pase 1967, Pase and Glendening 1965).

Watershed assessments suggested that streamflow was related to the interaction of precipitation and to the different native vegetation types occupying the upland watersheds of the Salt River Basin (Cooperrider and Sykes 1938, Cooperrider and Hendricks 1940, and Cooperrider et al. 1945). This finding encouraged further research on techniques of vegetation manipulations and the hydrologic responses to these manipulations. Of particular interest was development of a method for controlling deep-rooted brush species, and replacing them with shallower-rooted grass plants.

Early studies tested herbicides for shrub control (Cable 1957, Lillie et al. 1964), while other studies evaluated the combined use of herbicide and prescribed burning for controlling vegetation (Lindenmuth and Glendening 1962, Lillie et al. 1964, Pase and Glendening 1965, Pase and Lindenmuth 1971).

Short-term studies were also conducted at Workman Creek to supplement information gained from watershed-level studies. Investigations were conducted on the control of New Mexico locust and Gambel oak (Gottfried 1980, Davis and Gottfried 1983). The above- and below-ground biomass of locust was also related to water yield (Gottfried and DeBano 1984). Another concern of managers was the potential impact of pocket gophers on ponderosa pine seedling survival (Gottfried and Patton 1984).

Long-Term Studies

Important study areas dedicated to long-term research were located at the Base Rock lysimeters, Natural Drainages watersheds, and the Workman Creek watersheds.

Base Rock Lysimeters

Hydrologic research in the 1930s used lysimetry to obtain quantitative information on the water balance for different vegetation types because it offered a degree of experimental control that was not attainable using experimental runoff plots or small and large watersheds (Martin and Rich 1948). However, limitations associated with the use of lysimeters were recognized. Typical limitations included difficulty making the lysimeters large enough to reduce border effects and the disruption or destruction of the natural soil profile. The lysimeters constructed on the experimental forest mitigated these limitations by using large, undisturbed soil blocks overlying bedrock and, therefore, were named the "Base Rock Lysimeters." Three lysimeters (18 ft wide and 50 ft long) with undisturbed soil profiles were established on an area supporting a deteriorated stand of perennial grasses, snakeweed (*Gutlerrezia sarothrae*), and yerba-santa (*Eriodictyon angustifloium*) (<2% total plant cover). Revegetation treatments including seeding, fertilizing, and watering the lysimeters were carried out during 1934 and 1935. By 1942, the cover had increased to about 8% and consisted of mainly sprangletop (*Leptochioa dubia*), sideoats (*Bouteloua curtipendula*), and hairy grama (*B. hirsuta*). Three grazing treatments applied between 1942 and 1948 were:

- Overgrazing with sheep at the rate of 2 mature ewes for 4 days annually, usually in October.
- More moderate grazing at half the above rate.
- Ungrazed.

Natural Drainages Watersheds

Four chaparral-covered watersheds, called the Natural Drainages, were established on the Sierra Ancha Experimental Forest in 1934. These watersheds ranged in size from 9 to 19 acres. Precipitation and runoff were measured. The upper slopes of the watersheds contain diabase soils, which cover between 28% and 54% of the watersheds. Soils on the lower slopes are derived from quartzite. The original vegetation on these watersheds was sparse, with low density chaparral stands on southerly exposures.

Before treatment, crown cover of the chaparral shrubs was 20% to 25% compared with covers 2-to-3 times this density on the Whitespar and Three Bar watersheds (DeBano et al., Chapters 3 and 4 of this publication). Shrub live oak was the most abundant shrub. Livestock grazing in the area started about 1880 and continued until 1934, when experimental watersheds were established on the Sierra Ancha Experimental Forest.

The Natural Drainages watersheds were one of the first watershed-level studies used in the Central Arizona Highlands to evaluate the effect of grazing on vegetative change and on production of streamflow and sediment. Two of the four watersheds were grazed by cattle and horses for short periods during the fall and spring beginning in 1939, and 2 watersheds were the controls (Rich and Reynolds 1963). Herbaceous vegetation was quantified using meter-square quadrants. Streamflow was determined using 90^{o} V-notch weirs and sediment was measured in weir basins at the bottom of each of the 4 watersheds. These studies were terminated in 1952 when it was determined that the intensities of grazing used in the studies had no effect on total water yield or sediment trapped in the weir ponds (Rich and Reynolds 1963).

A growing interest in augmenting streamflow in the Central Arizona Highlands by manipulating native vegetation developed among water users in central Arizona during the 1950s. As a result, many of the research efforts during this period were initiated to evaluate the feasibility of increasing streamflow. A second experiment designed to determine the effects of chaparral cover manipulations on streamflow was started on the Natural Drainages watersheds in 1954 (Ingebo and Hibbert 1974). Chaparral cover was suppressed on 2 watersheds by treating the shrubs with herbicides, while the other 2 watersheds were maintained as control areas.

Workman Creek Watersheds

A major project was conducted on the Workman Creek watersheds to evaluate the hydrology of higher elevation mixed conifer forests and to determine the changes in streamflow and sedimentation from manipulating the forest vegetation. The 3 watersheds on Workman Creek are *North Fork*, *Middle Fork*, and *South Fork*. The treatments evaluated were selected to cover the range of water yields possible through manipulation or removal of the forest vegetation (Rich and Gottfried 1976). These treatments were not intended to be examples or recommendations for actual management applications, but instead they were used to obtain basic hydrologic information on streamflow responses to vegetation manipulations.

North Fork.—Studies on the North Fork of Workman Creek were designed to evaluate streamflow responses to clearing the forest cover in stages, starting on the wettest and progressing to the driest sites. The first treatment was implemented in 1953.

Riparian trees, mainly Arizona alder (*Alnus oblongifolia*) and bigtooth maple (*Acer grandidentatum*), growing adjacent to streams, springs, and seeps, were cut and their stumps were treated with herbicides to prevent sprouting. The cut removed 0.6% of the total basal area.

The next treatment on North Fork converted the moist site forest vegetation, mostly Douglas-fir and white fir, to grass on about 80 acres. Larger trees were harvested, and smaller and unmerchantable material was windrowed and burned. The cleared areas were seeded with grass species.

The final treatment on North Fork removed the adjacent dry-site forest of ponderosa pine trees and converted the site to grass (figure 4).

South Fork.—Treatments on South Fork of Workman Creek were designed to test the current forest management prescriptions of 1953. The watershed was harvested according to a standard single-tree selection prescription starting in June 1953.

The objective of the second treatment on South Fork was to convert mixed conifers to a pure ponderosa pine stand by removing the other conifer species, and to maintain the stand at a density of 40 ft^2 / acre. The hypothesis tested was that this forest density should optimize both timber and water production.

Middle Fork.—Middle Fork watershed was left untreated so it could be used as a control for quantifying changes in streamflow after treating North Fork and South Fork watersheds.

Cooperators

A number of organizations cooperated with the Rocky Mountain Station's research effort on the Sierra Ancha Experimental Forest. The Salt River Water Users' Association provided financial support for the treatments on Workman Creek. The Tonto National Forest assisted with implementation of these forest management treatments. Faculty and students from Arizona State University and the University of Arizona conducted collaborative experiments on Sierra Ancha. University-sponsored research has increased in recent years.

Results

A status-of-knowledge publication presented the results of the water yield improvement experiments and other research conducted on the watersheds through the early 1970s (Rich and Thompson 1974). This publication reported on the opportunities for increasing water yields and other multiple use values in mixed conifer forests. Many of these results were later refined, expanded upon, and subsequently reported on in other publications. A brief discussion of the results is presented below; details are in the cited literature.

Conclusions from the Base Rock Lysimeters showed that (Martin and Rich 1948):

- The major portion of annual water yield occurred during winter as sub-surface flow from long-duration, low-intensity storms.
- Most surface run-off and soil erosion occurred during summer storm events from short-duration, high-intensity thunderstorms.
- Overgrazing caused increases in summer surface runoff and erosion and decreases in areal infiltration capacities, while the amount of winter water

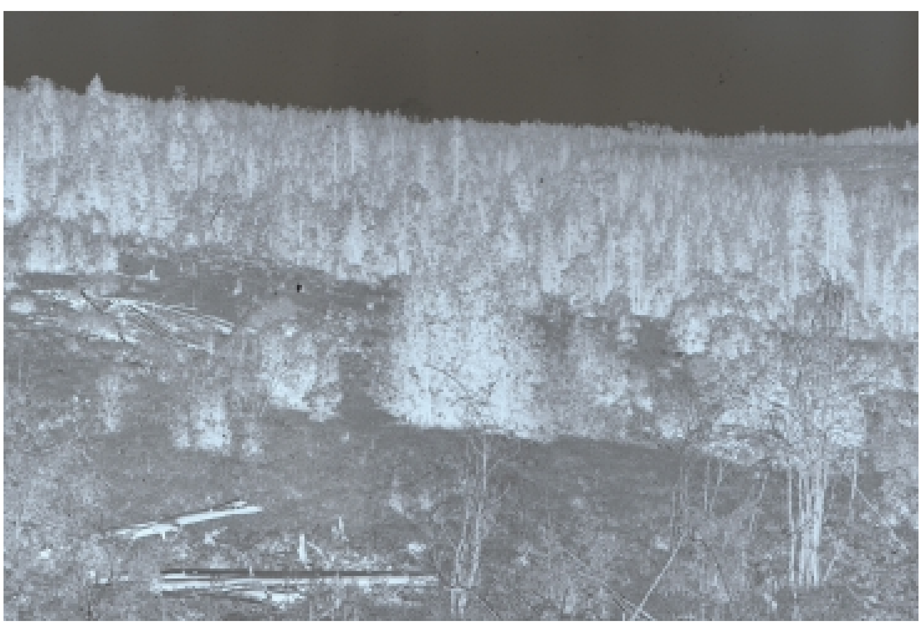

Figure 4. Overstory manipulations on the North Fork of Workman Creek Watershed.

percolation was independent of the grazing treatment. Soil losses during summer storms increased from 60 to 307 tons / mi^2 on heavily grazed plots compared to theungrazed controls. In contrast, winter soil losses only increased from 15 to 68 tons / mi^2 on moderately grazed plots.

- Results from late summer frontal-type storms were intermediate between those from summer and winter storm events.

Overall, major amounts of sediment-free water come from areas with good grass cover and soil erosion is greatest where vegetation densities have been decreased, as by overgrazing.

Results from herbicide studies on the Natural Drainages watersheds indicated:

- There was 3-times more grass, forb, and half-shrub production on the treated areas having quartzite soils than on similar soils on the control areas (Pond 1964). No differences in plant production were observed on the diabase soils.
- An increase of 22% in streamflow occurred on treated areas (Ingebo and Hibbert 1974). Pretreatment average annual streamflow was 1.65 inches.
- The treated areas showed a 30% increase in quickflows, a 32% increase in delayed flows (the rising and falling stages of a streamflow hydrograph), and a 26% increase in peak flows (Alberhasky 1983).
- A decline of 72% in annual sedimentation was attributed to the increase in grass cover on the treated areas.

Streamflow increases from vegetation manipulations were attributed to lower evapotranspiration demands by the replacement grass cover. The streamflow increases from the Natural Drainages watersheds were low compared to other chaparral areas (Hibbert et al. 1974); this was related to the initial low density of shrubs and to the southeastern exposure of the area that results in relatively high energy inputs for evapotranspiration.

Results from the 3-stage removal of the forest overstory on North Fork of Workman Creek indicated:

- Streamflow increased from both the moist- and dry-site treatments, but not from the riparian areas.
- Evaluation of the treatments in 1979, after 13 years of data collection, showed that the increases had remained stable (Hibbert and Gottfried 1987).
- Winter stormflows responded less to treatment than summer stormflows, although the actual volumes of winter runoff were larger (Hibbert and Gottfried 1987).
- Sediment yield increases were low (Rich et al. 1961). Most sediments moved during high-volume stormflows, and most material originated from the channels and main logging road (Rich and Gottfried 1976).

Results from thinning the forest overstory to 40 ft^2 / acre on South Fork of Workman Creek showed:

- Water yield increases, which remained constant for 13 years (Hibbert and Gottfried 1987). Severe forest overstory removal (to 40 ft^2 / acre) to encourage growth of the ponderosa pine forests is not recommended for present day management. An adverse reaction of the public would likely be created because of the esthetic of such a treatment and because of the perceived influence such a thinning would have on other components of the ecosystem.
- There was little effect on soil movement (Rich 1962, Rich and Gottfried 1976). A wildfire on the upper area of South Fork produced the greatest amount of soil disturbance.

Implications

Research on the Sierra Ancha Experimental Forest has contributed to the knowledge base of hydrology, watershed management, and basic ecology for over 65 years. These studies provided:

- Guidance for subsequent watershed research programs in chaparral and mixed conifer forested ecosystems.
- Information on water yield responses to vegetation manipulation that is useful to land managers and researchers.
- Research findings that continue to be implemented when designing multiple resource ecosystem management treatments.

Current Status

Most of the hydrologic measurements on the Sierra Ancha Experimental Forest were discontinued in the late 1970s and 1980s in response to a shift in USDA Forest Service research priorities. Currently, only the Upper Parker Creek weir, the Sierra Ancha weather station, and the USDA Natural Resources Conservation Service snow measuring station are active. Ecologically-oriented research continues to a limited extent.

Arizona State University entered into a lease agreement with the Forest Service in 1983 to use the Parker Creek Headquarters complex. The experimental forest and surrounding Tonto National Forest continues to be used for faculty and graduate student ecological research and summer field classes. The Parker Creek complex is used for Forest Service, university, and conservation group meetings. The Sierra Ancha Experimental Forest has a tradition of natural ecosystem ecology and management research and the potential for future contributions.