Forest Service Watershed Research in the Southwest

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Abstract

Forest watershed research in the Southwest started in Arizona because of concerns about sediment inputs into the newly constructed Roosevelt Reservoir. The Summit Plots were established in 1925 to study the effects of vegetation establishment and mechanical soil stabilization on stormflow and sediment yields. In 1932 the Forest Service dedicated the Parker Creek Experimental Forest, later renamed Sierra Ancha Experimental Forest, for watershed research. In the 1950s and 1960s Forest Service research expanded to other areas such as Three-Bar, Brushy Basin, Whitespar, Mingus, Battle Flat, Beaver Creek, Castle Creek, Thomas Creek, and Willow Creek. The purpose of this expansion was to cover the full range of forest and woodland vegetation types from chaparral to pinyon-juniper, ponderosa pine, mixed conifer, and subalpine forest. Other smaller research sites were added in Arizona and New Mexico over the ensuing years to examine the watershed effects of grazing, wildfire, and riparian management. This paper examines the history of the Forest Service's watershed program in the Southwest and its usefulness for forest land management.

Keywords: watershed management, forests, ponderosa pine, mixed conifer forests, chaparral, Southwest

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Introduction

A common impression of the southwestern United States is that it is an area of vast deserts covered with cacti and low shrub species. Actually, the topography and vegetation of the Southwest are very diverse, including high plateaus and mountains that extend over 3,660 m in elevation.

The higher elevations receive relatively large amounts of precipitation, often in the form of snow, and support forests of ponderosa pine (*Pinus ponderosa*) and mixed conifers. Forested watersheds are the sources for much of the surface water for the major river systems within the region, including the Colorado, Salt and Verde in the Gila River Basin, and Rio Grande. The waters from the Salt and Verde Rivers in Arizona and Rio Grande in New Mexico are one of the reasons for the pre-historic American Indian and later European-American settlements and subsequent rapid growth of the Phoenix and Albuquerque Areas.

The need for watershed protection was recognized early. The Tonto National Forest in central Arizona, for example, was established in 1905 to protect the Salt River watershed and the Theodore Roosevelt Dam, the first reclamation project in the United States, which was under construction at the time.

Sound watershed management should be based on research. Watershed management research was initiated in Arizona in the 1920s when concerns developed that accumulations of sediment behind Roosevelt Dam would compromise the reclamation project. Research subsequently expanded to answer managers' questions about the hydrology of upland watersheds and efforts to manage forests and woodlands for augmented stream flows in the context of multiple resource management. Forest managers incorporated research results into management activities and into multiple-use planning.

Current watershed management efforts are aimed at maintaining or improving watershed conditions and water quality and at assessing the impacts of recent disastrous wildfires on hydrology and watershed condition. This paper reviews past forest watershed management research in the Southwest, management to reduce erosion and improve water quality from forested areas, and the impacts of fire on forest watershed values.

The Setting

Topography

The topography of the Southwest is very diverse. Elevations in Arizona vary from less than 42 m near the border with California and Mexico, to more than 3,862 m on top of the San Francisco Peaks near Flagstaff. Twenty-three mountain ranges are identified within New Mexico; the highest mountain has an elevation of 4,012 m. Arizona is divided into the Colorado Plateau, the intermediate Central Highlands, and the Basin and Range geological provinces that are located from the north to the south. Each of these provinces contains mountains, canyons, and valleys, cliffs and plains that were formed and influenced by geological events (Lowe 1964). New Mexico is divided into three topographic zones. These include a Rocky Mountain zone, the Plains zone of the eastern border with Texas and Oklahoma, and the Intermountain Plateau and Valley zone.

Climate

The climate is characterized by variable frontal precipitation in winter from the Pacific Ocean, an arid pre-summer, and summer rains that are predictable in timing and amount at a given station but vary from site to site. The summer moisture comes primarily from the Gulf of Mexico in a monsoon-like seasonal pattern. The proportion of winter to summer moisture varies throughout the region with southern and eastern areas being more dependent on summer precipitation than more northern and western sites. The summer season is characterized by convective storms that are often associated with high intensity rainfall events. Occasional tropical storms enter the region from the Pacific Ocean in late summer.

Desert areas of the Southwest average less than 25 mm of annual precipitation (Sellers and Hill 1974); however mountainous regions may average between 760 and 1,015 mm as rain and snow. Elevation is a key factor influencing the amounts of precipitation recorded in the Southwest. The highest mountains receive the largest amounts of moisture, primarily as snow. Higher precipitation and lower temperatures provide the necessary environment for forests to occur. Some of the plateaus, which are more than 1,830 m in elevation, are quite arid due to rain shadow effects.

Vegetation

The Southwest contains six life zones from deserts to alpine tundra based on vegetation types and varying by elevation and aspect (Lowe 1964). Ponderosa pine and mixed conifer forests are of prime interest because of their importance to watershed and natural resource management.

Ponderosa pine forests occupy about 2.38 million ha in the region (Van Hooser et al. 1993, O'Brien 2002). Ponderosa pine forms almost pure stands in association with a variety of grasses and other herbaceous species. The species is found from about 1,600 to 2,600 m in elevation and is often associated with pinyon (*Pinus edulis*), alligator juniper (*Juniperus deppeana*), and Gambel oak (*Quercus gambelii*) at its lower range, and with Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) at higher up.

The southwestern mixed conifer forests occupy about 809,000 ha between 2,400 and 3,400 m in elevation. These forests are a combination and intermixture of forest species and types. The dominant tree species are Douglas-fir, ponderosa pine, white fir (*Abies concolor* var. *concolor*), Engelmann spruce (*Picea engelmannii*), blue spruce (*P. pungens*), corkbark fir (*A. bifolia*), southwestern white pine (*P. strobiformis*), and quaking aspen (*Populus tremuloides*). Limber pine (*P. flexilis*) stands are only found in northern New Mexico.

The Southwestern forests were noted historically for their production of timber when the railroads entered the region in the 1870s. The value of forested watersheds was recognized in the nineteenth century. Current management on non-reserved lands is aimed at multiple-use of the forest resources for wildlife habitat, a number of threatened, endangered, and sensitive species, livestock, and recreation. The latter has grown in importance with the recent increases in the Southwest's population.

Watershed Management Research

Research scope

A complete coverage of the research conducted on the Forest Service watersheds in the Southwest is beyond the limitations of this manuscript. Work was conducted on the complete scope of watershed management topics. This includes management topics such as harvesting, thinning, site preparation, chemical vegetation management, grazing, road construction, recreation, and cumulative effects. Specific process-level studies examined water yield, snow hydrology, water quality, erosion, heavy metals, sedimentation, aquatic biology, nutrient cycling, etc, A more complete description of the details of this research program can be found in Baker (1999) and Gottfried et al. (2003). The focus of this narrative is on the history of Forest Service's key watershed research sites.

History of watershed research

Initial watershed research efforts were directed in determining methods of controlling erosion from lower elevation chaparral sites surrounding Roosevelt Reservoir. Chaparral is a vegetation type dominated by evergreen, sclerophyllous shrubs. Soil erosion was seen as a threat to the longevity of the dam and the general reclamation project along the Salt River. The Summit watersheds were established in 1925 to address the problem.

The Forest Service's Southwestern Forest and Range Experiment Station (now the Rocky Mountain Research Station) established the Parker Creek Experimental Forest in 1932 in the Sierra Ancha Mountains northeast of Roosevelt Reservoir and enlarged and renamed the forest in 1938 as the Sierra Ancha Experimental Forest. The 5,190 ha experimental forest, because of its broad elevational range (1,080 to 2,355 m), includes seven vegetation types from desert-shrub to mixed conifer forests (Pase and Johnson 1968). The research objective 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 of the Southwest (Gottfried et al. 1999a).

Both plot and watershed research was initiated at Sierra Ancha. Much of the early work concentrated on grazing effects, primarily in the chaparral shrublands that cover about 57% of the Experimental Forest. However, major watershed studies were begun in the 1930s at the Workman Creek watersheds in the mixed conifer-ponderosa pine forests and on Parker Creek and Pocket Creek that supported a mixture of chaparral stands and conifer forests, depending on aspect. The initial effort at Sierra Ancha was designed to determine the basic hydrologic relationships for forested watersheds in the Southwest.

An effort was launched in 1955, during a period of extended drought, to determine the feasibility of increasing stream flow by manipulating the plant cover in the different vegetation types within the Salt and Verde River Basins (Fox et al. 2000). Although watershed treatments were in progress at the time in the mixed conifer stands at Workman Creek, additional research was initiated to evaluate the chaparral, pinyon-juniper, and ponderosa pine forests of central Arizona and other mixed conifer watersheds in eastern Arizona. The goal of this work was to determine the effects of vegetation manipulations on the other natural resource products and uses as well as on runoff. A review of research results determined that augmented streamflow was possible where annual precipitation exceeded 460 mm (Hibbert 1979).

Research at a number of chaparral sites in Arizona (Three Bar, Whitespar, Mingus, Battle Flat, etc.) demonstrated that runoff could be increased when the vegetation was growing on deep soils or porous parent materials (DeBano et al. 1999). However, research in coniferous woodlands dominated by pinyon and junipers (*Juniperus* spp.) generally did not show increased water yields, even when the entire tree cover was removed (Baker 1984). The best opportunities for increasing water production in the context of multiple resource management were demonstrated to be in the ponderosa pine and mixed conifer forests.

Workman Creek

The initial research in these forests was conducted on the three Workman Creek watersheds in the Sierra Ancha Experimental Forest to evaluate the hydrology of higher elevation mixed conifer forests and to determine the changes in streamflow and sedimentation from manipulating the forest cover (Gottfried et al. 1999a). The treatments were selected to cover the range of water yields possible through manipulating or removing the forest vegetation. Some treatments were designed to obtain basic hydrological information, and others were designed to test common or potential silvicultural prescriptions.

The basic experimental design was to treat the North Fork and South Fork and hold Middle Fork as the hydrologic control. Studies on North Fork were designed to evaluate streamflow responses to clearing the forest cover in stages, starting on the wettest and progressing to the driest sites (Rich and Gottfried 1976, Gottfried et al. 1999a). The first treatment in 1953 removed the riparian vegetation along the stream channel and around springs. In 1958, the mixed conifer stands nearest the channels were commercially harvested and small trees and unmerchantable material were pushed and burned. The final treatment in 1966 was the harvesting of drier site ponderosa pine stands.

The initial treatment on South Fork in 1953 was to evaluate the common single-tree selection prescription. A wildfire burned through part of the watershed in 1957, and the two events resulted in the removal of 45% of the initial stand basal area. The second treatment in 1966 was designed to convert the mixed conifer forest into a pure ponderosa pine forest by harvesting the Douglas-fir and white fir and planting pine seedlings. The eventual goal was to thin the resulting stand to 9.2 m^2 ha^{-1} of basal area to determine if this density would optimize both tree and water production.

The two treated watersheds and the control watershed were burned by the Coon Creek Fire in 2000 and were re-instrumented after a 17-year hiatus. Current research is evaluating the impacts of the severe wildfire on mixed conifer hydrology and erosion and sedimentation.

White Mountain watersheds

Watershed management research moved into the White Mountains of eastern Arizona. soon after initial results from Workman Creek were reviewed. The initial objective was to determine if results from Workman Creek could be confirmed and if they were transferable to other mixed conifer areas (Gottfried et al. 1999b). One concern was that the relatively large openings of more than 32 ha would be unacceptable for multiple-use forest management and compromise prescriptions that benefited water and timber production and wildlife habitat. Three sets of paired experimental watersheds were established on Castle Creek, which supported high elevation stands of ponderosa pine and mixed conifers, and on Willow and Thomas Creeks, which supported dense mixed conifer stands.

The results from Workman Creek indicated that even-aged management could maintain long-term timber production and improve water yields (Rich 1972). The experiments on Castle Creek, where the West Fork (364 ha) was harvested and East Fork (471 ha) served as the hydrologic control, were designed to test this hypothesis. The watersheds are located between 2,388 and 2,616 m in elevation. In 1965, one-sixth of the stand was harvested in irregular blocks fitted to stand conditions and the remaining stand was put into optimum growing condition by thinning and sanitation operations. The idea was to create conditions where trees would achieve a desired size within 120 years and where one-sixth of the stand would be harvested every 20 years. The harvest reduced the stand basal area from 31.0 to 14.5 m^2 ha^{-1}. Harvested blocks were planted with ponderosa pine seedlings to ensure adequate regeneration.

A second treatment was initiated in 1981 to test the impacts of pre-harvest prescribed fire as a method of reducing heavy natural fuel loadings. Aggressive fire suppression has been partially responsible for the accumulations of heavy fuel loadings within many southwestern ecosystems that have increased the potential of severe, stand-replacing wildfires. The stable increases in streamflow since 1967 allowed the fire treatment to be applied to East Fork and the West Fork to become the control watershed. The fire reduced surface fuels on approximately 43% of the watershed, but caused little mortality to the overstory.

The second test of the effects of timber management on water augmentation was conducted on the East and West Fork watersheds of Willow Creek, a relatively short distance from Castle Creek. West Fork has an area of 117 ha and East Fork contains 198 ha; elevations on the experimental area range from 2,682 to 2,835 m. The silvicultural prescription on East Fork was similar to the one used on the West Fork of Castle Creek, but the Willow Creek watersheds are at a higher elevation site that is dominated by mixed conifer stands containing an important spruce-fir component. Heavy logging removals, which contributed to excessive wind damage, compromised the original research objectives. The designated openings were often indistinguishable from the areas that had been marked as residual thinned stands; 62% of the watershed was in openings (Gottfried 1983).

Regeneration numbers and stocking recovered because of vigorous quaking aspen suckering.

The third watershed management experiment in the White Mountains was conducted on the two Thomas Creek watersheds that supported an undisturbed, old-growth mixed conifer forest. The South Fork (227 ha) and the North Fork (189 ha) range from 2,560 to 2,835 m in elevation. The objective was to demonstrate and evaluate the knowledge of integrated resource management for southwestern mixed conifer forests (Gottfried 1991).

Beaver Creek watersheds

The southwestern United States experience a drought period during the 1950s, and land owners and managers were concerned that the increases in stand densities in Arizona's ponderosa pine and pinyon-juniper woodlands contributed to reduced surface runoff and amounts of forage for livestock (Fox et al. 2000). A review of existing information determined that replacing high water-using trees and shrubs with low water-using grasses and forbs would increase water yields. However, there were concerns about the effects of vegetative manipulations on other natural resource products.

The Beaver Creek watershed study became a significant component of the effort to evaluate the feasibility of manipulating vegetation by silvicultural treatments to increase water yields and other multiple resource benefits. The Beaver Creek complex encompasses 111,289 ha, south of Flagstaff in the Verde River Basin. Average elevations ranged from 2,054 to 2,225 m. Average winter precipitation ranges from about 550 to 510 mm at Beaver Creek with 60% occurring mostly as snow during then winter (Baker 1986). A multi-discipline team, including forest, wildlife, and range scientists, hydrologists, and economists was assembled in 1960 for the project. A large number of researchers and managers from the Forest Service, other federal and Arizona State agencies and universities cooperated with the Beaver Creek Project throughout the research effort.

Twenty pilot experimental watersheds were instrumented to determine the effects of a variety of land management treatments on stream flow and erosion and on the other natural resources. The 12 watersheds that supported ponderosa pine stands and range from 66 to 730 ha in size are the focus of this discussion. Sub-drainages were also instrumented within the pilot watersheds to refine the findings from the larger watersheds. The remaining eight watersheds included six that were covered by pinyon-juniper woodlands and two large, untreated ponderosa pine watersheds of more than 4,856 ha in size. Since basalt is the main parent material at Beaver Creek, additional watersheds were established on limestone and sandstone sites in eastern Arizona to determine the hydrology of these areas but these were not treated.

Results from the Beaver Creek experiments have been reported in nearly 700 publications, including USDA Forest Service publications, journal articles, and special publications on specific topics, and dissertations and theses (Baker and Ffolliott 1998). The Beaver Creek experiments demonstrated that manipulating the forest vegetation can produce short-term increases in stream flow and that increases generally occur during years with above average precipitation (Baker 1986). However, these increases also occur when the reservoirs are near capacity and it is difficult to effectively control the additional runoff. Vegetation manipulations for runoff augmentation can benefit wildlife, forage production, timber and amenity values. Results from Beaver Creek have not been limited in applicability to the Southwest but are of national and international interest.

Summary

Forest watershed management has been an important aspect of forestry in the southwestern United States since the early 20th century. A watershed research program was initiated in the 1920s to gather fundamental information about the hydrology of forested watersheds. In the future, watershed management will emphasize watershed improvement practices, sustaining riparian ecosystems, and managing watersheds to meet society's growing demands for limited watershed resources. Sound land stewardship, now and in the future, requires partnerships among the general public, land users and watershed managers and a continued investment in watershed science.

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