Chapter 5

Interdisciplinary Land Use Along the Mogollon Rim

Malchus B. Baker, Jr. and Peter F. Ffolliott

Introduction

The amount of water stored in the Salt River Project reservoirs during the middle 1950s was low and, as a consequence, apprehension arose among some residents of the Salt River Valley that a serious water shortage would soon occur. Groundwater supplies in the Valley were also being rapidly depleted, and pumping costs were steadily rising. Long-term studies at Sierra Ancha Experimental Forest had shown some potential for increasing runoff by converting chaparral shrublands to grass (Gottfried et al., Chapter 2 of this publication). Therefore, a belief existed that the yield of water from the Salt and Verde Watersheds could be increased by drastic, but fairly simple, conversions of the various vegetation types. Suggestions for water yield improvement included widespread burning of chaparral, eradication of pinyon-juniper woodlands by burning and mechanical methods, and prescribed burning in ponderosa pine forests.

Several ranchers met with a USDA Forest Service representative and an official with the Salt River Project on the Beaver Creek watershed near Flagstaff to address this issue in the summer of 1955. People at this meeting were concerned that the flow of streams and the amount of livestock forage on watersheds in the Salt-Verde River Basins were being reduced by increasing densities of ponderosa pine saplings. As a result of this meeting, the University of Arizona was commissioned to investigate the potential for increasing water yields from the state's forests and rangelands. The findings of this study were contained in a publication entitled "Recovering Rainfall: More Water for Irrigation," commonly referred to as the Barr Report (Barr 1956). The study suggested that surface runoff from mountain watersheds might be increased by replacing high water-using plants, such as trees and shrubs, with low water-using grasses and forbs. This report resulted in a demand for an immediate action program to ascertain the feasibility of improving water yields through vegetative manipulations.

But many questions as to the effects of such vegetative manipulations on other natural resource products and uses of the watersheds remained unanswered, and the effectiveness of most of the practices proposed was largely untested. In response to the demand for increased water yields, the Arizona Water Program of the USDA Forest Service was initiated in the late 1950s to evaluate the feasibility of selected vegetative management programs to increase water yields and other multiple resource benefits in the Salt River Basin (Arizona State Land Department 1962). The Beaver Creek watershed became a significant component of this program.

Beaver Creek Watershed

The Beaver Creek watershed encompasses 275,000 acres on the Coconino National Forest, upstream from the junction of Beaver Creek and the Verde River (figure 13). This watershed is part of the Salt-Verde River Basin, which is a

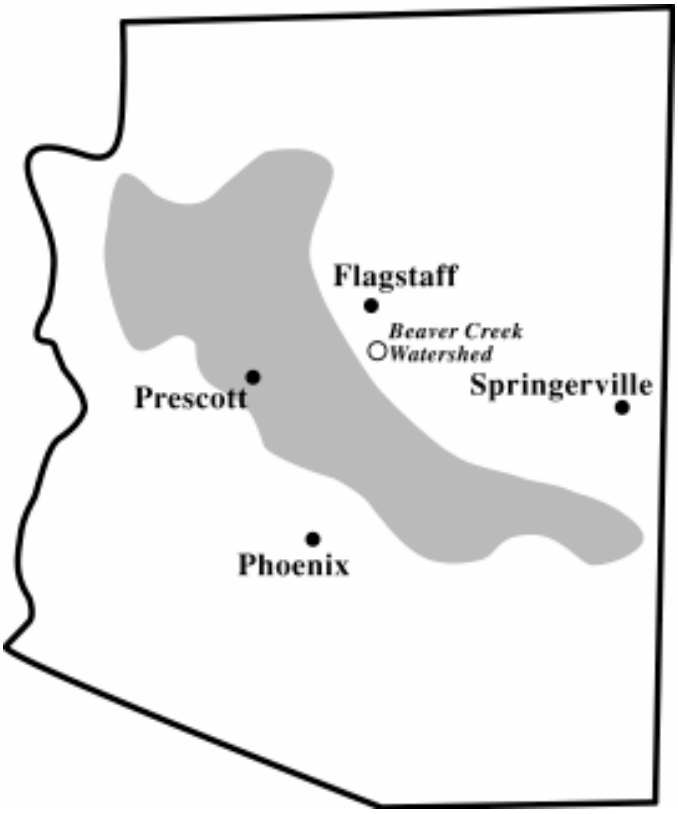

Figure 13. Beaver Creek watershed in the Central Arizona Highlands.

major river drainage in central Arizona. The Salt and Verde Rivers provide much of the water for Phoenix and other communities in the heavily populated Salt River Valley. The Beaver Creek watershed was selected for research because it contains extensive areas of ponderosa pine forests and pinyon-juniper woodlands, which are found in the Central Arizona Highlands and throughout the Southwest (Worley 1965).

Beaver Creek Project Design

The Beaver Creek Project was initiated by the USDA Forest Service as a pilot study in 1957 to test some of the Barr Report hypotheses. The original plan was to apply generally accepted management practices intensively to one large watershed, while retaining a similar watershed in an untreated condition to determine whether a change in runoff could be detected. Management practices contemplated were:

- Thinning and debris disposal in ponderosa pine forests to improve the growth of residual trees.
- Eradication of the pinyon-juniper woodlands to enhance livestock grazing conditions.

Isolation of the effects of certain land treatments was necessary to concentrate on treatments that were thought to be effective in improving water yields. A system of smaller pilot watersheds was established to study these effects.

Pilot Watersheds

Since the standard program of applying management practices to large areas of vegetation would take several years to perform, smaller watersheds were selected for treatment to obtain results earlier and to determine if local changes in runoff could be realized downstream. Twenty pilot watersheds were established between 1957 and 1962 to test the effects of vegetation management practices on water yield and other resources (Brown, et al. 1974). Of the 20 watersheds, 18 were from 66 to 2,036 acres in size; 3 in the Utah juniper type, 3 in the alligator juniper type, and 12 in the ponderosa pine type. The other 2 catchments, encompassing 12,100 and 16,500 acres of ponderosa pine forests, were set aside to demonstrate the effects of management practices on areas the size that managers work with operationally.

Stream gauges were built at the outlets of all watersheds, while sediment-measuring devices, in which suspended sediments and bedloads could be collected, were constructed on some. A network of precipitation gauges was installed throughout the study area (Baker 1982). Timber, herbage, and wildlife resources were inventoried (the latter by the Arizona Game and Fish Department) on a system of permanently-located primary sampling units established on each pilot watershed (Brown et al. 1974, Clary et al. 1974). Point sampling techniques were used to monitor stand structures, tree-stem form, and species composition over time. These sampling points were also center-points for plots of varying sizes on which regeneration success, herbaceous vegetation, wildlife populations and habitat preferences, and hydrologic conditions were sampled.

Yields of water, timber, forage, and other natural resource products from the pilot watersheds were determined before any treatments were applied to provide the needed pre-treatment calibration information. One watershed was then altered through vegetative manipulation and another held in its original condition as a control for evaluations of potential changes in these yields. If a resource change was detected after treatment, it was attributed to the treatment implemented.

To refine the findings from the studies on the pilot watersheds for use over a wide range of conditions, 24 smaller watersheds, 12 to 40 acres in size, with more uniform soil, plant life, and topography, were established in the early 1970s to sample the range of diverse ecological characteristics in the ponderosa pine forests (Brown et al. 1974). To compare the findings from watersheds with soils developed on basalt and cinders (55% of the Salt-Verde River Basin) to watersheds on soils formed from sedimentary rocks (45% of the Salt-Verde River Basin), 3 of these smaller watersheds were established on limestone soils (Campbell et al. 1977) and 4 were installed on sandstone soils (Ffolliott and Baker 1977).

Responsibilities

The Beaver Creek watershed, located on the Coconino National Forest, is administered for a full range of multiple use benefits. National forest personnel installed many of the measuring structures and devices, performed the land treatment prescriptions, and accomplished the normal protection and management functions.

Up dated evaluation techniques would be required if the Beaver Creek Project was to meet its objective. As a consequence, the assistance of Forest Service Research was necessary. A team of forest, range, and watershed *scientists*, *economists*, and *hydrologists* was assigned full-time to the project in 1960. This team of Rocky Mountain Forest and Range Experiment Station employees, in collaboration with their cooperators, developed the neces-

sary research studies to support the project, and helped national forest personnel design the treatments that were applied to the pilot watersheds. This team was also responsible for collecting and analyzing much of the data obtained on the pilot watersheds before and after treatment.

Wild Bill Studies

Knowledge of the relationships between various land products and uses is required for effective multiple use planning. If managers modify an area in favor of one product, what will be the effect on other products? Since cattle production was an integral part of the Beaver Creek Project, an area of approximately 1,300 acres of ponderosa pine-bunchgrass range was established to develop relationships between beef and forage production under different overstory densities (Pearson 1972). The area, known as the Wild Bill Cattle Allotment, is northwest of Flagstaff on the Coconino National Forest. Specific objectives for this study were to:

- Determine the effects of various tree overstories on quantity, quality, and composition of forage.
- Establish the relationships between beef and timber production at various tree overstory densities.

Information obtained on Wild Bill was used to estimate changes in beef production following the various treatments applied to the Beaver Creek watershed. This aspect of the project resulted in a number of publications related to forage digestibility by cattle, plant phenology and forage production, and beef-forage-timber relationships (Clary et al. 1975, Pearson 1972, 1973, Pearson et al. 1972).

Biosphere Reserve

In 1976, the Beaver Creek watershed was designated a biosphere reserve, a component of a worldwide network of biosphere reserves in UNESCO's Man and the Biosphere (MAB) Program. Previously, the governors of Arizona and the State of Durango, Mexico, signed an agreement entitled "Comparative Studies of Dry Forests in Western North America" to improve the scientific knowledge and technology of Mexico and the United States. Two sites, the designated La Michilia Biosphere Reserve in Durango, Mexico and the designated-to-be Beaver Creek Biosphere Reserve, were selected as the primary study areas for this bi-national program.

Although the 2 biosphere reserves contained dry forests and woodlands, La Michilia and the Beaver Creek watershed were distinct from one another in some respects. Little information on multiple resource management had been gathered at La Michilia, an area partly used for timber production, livestock grazing, and hunting. Beaver Creek, however, had been managed actively for multiple resource benefits by the USDA Forest Service and, as mentioned, was the center of an intensive multiple-resource management, research, and testing program. While dissimilar with respect to past management and research activities, the 2 biosphere reserves shared similar climatic, topographic, and land use characteristics. Objectives of this bi-national program were to:

- Analyze the growth, yield, and quality of timber resource for primary wood products.
- Investigate the levels of forage production and associated cattle, other livestock, and wildlife production on the representative grazing lands.
- Determine the habitat requirements and the distribution of preferred habitats for indigenous wildlife species and cattle, with an emphasis on food habitats, population dynamics, carrying capacities, and potential competition.
- Develop a set of simulation techniques to predict the environmental and socioeconomic consequences of alternative land use practices and provide a basis to identify improved methods for sustainable multiple resource management and environmental preservation.
- Produce a computerized data management system to assist decision-makers and managers in achieving wise use and proper conservation of all natural resources.

From information obtained from the 2 biosphere reserves, alternative land management practices could be proposed to meet the local needs of forage for livestock and wildlife and timber for lumber and fuelwood supplies while attaining conservation through environmentally-sound management practices. Publications from this bi-national program are reported in a Department of State publication in which MAB-sponsored research in the temperate regions of the world was reviewed (Ffolliott and Bartlett 1991).

Cooperators

By the late 1960s, the major objective of the Beaver Creek Project had evolved into evaluations of the effects of

vegetative treatments on all of the natural resources and uses of national forest lands, rather than on only water yields (Brown et al. 1974). Therefore, cooperation of many agencies, institutions, and organizations was enlisted. The help of the U.S. Geological Survey was secured to install and service specific stream gauges. The Arizona Game and Fish Department evaluated the effects of treatments on wildlife populations and habitat conditions. Research by universities in the state complemented the efforts of scientists from the Rocky Mountain Forest and Range Experiment Station. The advice and support of other groups, including the Salt River Project, Soil Conservation Districts, cattle-grower's associations, timber industries, and others, was solicited and made available.

One of the most important groups was the Arizona Water Resources Committee (AWRC); a committee comprised of civic-minded, thoughtful representatives of practically every citizens' group interested in public land management. The AWRC worked closely with the supervisor of the Coconino National Forest, supervisors of other national forests in the Central Highlands, the regional forester, and the director of the Rocky Mountain Forest and Range Experiment Station in an advisory and supporting capacity. The AWRC also played a critical role in securing the necessary financial support for much of the work accomplished by the Beaver Creek Project and the Arizona Watershed Program as a whole.

Results

Results from the experiments and studies conducted on the Beaver Creek watershed have been reported in nearly 700 publications including USDA Forest Service releases, journal articles, and special publications on specific topics (Baker and Ffolliott 1998). While the details of all of these results cannot be presented here, highlights of the major findings are presented.

Two status-of-knowledge publications presented the results of water yield improvement experiments and other research conducted on the pilot watersheds through the early 1970s. One of these publications reported on the opportunities for increasing water yields and other multiple use values in the ponderosa pine forests (Brown et al. 1974). The other publication described the effects of removing pinyon-juniper woodlands on natural resource products and uses (Clary et al. 1974). Many of these results have been refined and, in some cases, expanded upon in subsequent publications listed in an annotated bibliography of 40 yr of investigations on the Beaver Creek watershed (Baker and Ffolliott 1998). A brief discussion of the results is presented below; details are in the referenced bibliography and cited literature.

Natural resource responses to manipulation of ponderosa pine forests by total clearcutting (figure 14a), stripcutting in uniform or irregular strips (figure 14b), strip shelterwood cutting, thinning by group selection (figure 14c), a combined shelterwood-seed tree silvicultural treatment, patch cutting to improve wildlife habitats, and grazing on a watershed converted to herbaceous plants include:

- Annual water yield increases of 1 to 2 inches were realized in the initial (up to 10 yr) post-treatment periods as a result of various intensities and patterns of forest overstory reduction (Baker 1986). Considering multiple use objectives, an average annual increase of almost 0.6 inch is possible on the more productive sites (Brown et al. 1974). These increases in water yields diminished over time, approaching pretreatment levels after 10 or fewer yr.
- No meaningful changes in total sediment production or water quality occurred as a result of the treatments applied in ponderosa pine forests. However, relationships between the amount of sediment in suspension and streamflow discharge differed among the treated watersheds (Dong 1996). Highest sediment concentrations occurred after clearcutting, followed, in order of decreasing concentration, by stripcutting, thinning by group selection, and the combined shelterwood-seed tree silvicultural treatment.
- Repeated inventories of the timber resource indicate that volume production has been maintained in many cases, although at generally lower levels than those represented by pre-treatment conditions. Exceptions to this finding are on a watershed that was totally cleared in 1966 and 1967. Another watershed had also been converted from ponderosa pine forest to grass in 1958 and subsequently subjected to grazing in the spring and fall starting in 1968. While these 2 watersheds are currently stocked by stands of Gambel oak and alligator juniper, they have been withdrawn from pine production due to inadequate natural pine stocking (Ffolliott and Gottfried 1991a).
- Reductions in the density of ponderosa pine forest overstories have generally resulted in increases in the production of herbaceous plants (Bojorquez-Tapia et al. 1990) and vice versa. These increases can approach 500 lbs / acre after complete overstory removal including forage and non-forage plants. Average pretreatment forage production was 200 lbs / acre.

Figure 14a. Vegetation treatments in ponderosa pine forests on Beaver Creek Watershed including clearcutting (*top*), strip-cutting in uniform strips *(middle*), and thinning by group selection(*bottom*).

- Reducing densities of ponderosa pine forests has also increased food for deer and elk, while retaining protective cover (Larson et al. 1986). Residual dense stands, often referred to as dog hair thickets, have frequently provided bedding cover. Total clearcutting is detrimental to big game and Abert squirrel (*Sciurus abertii*), although cottontail habitat can be enhanced when slash and Gambel oak thickets are retained (Ffolliott 1990).
- Public responses to vegetative treatments applied to the Beaver Creek watersheds were variable. Through applications of Scenic Beauty Estimation (SBE), which provides quantitative measures of aesthetic preferences for alternative landscapes (Daniel and Boster 1976), natural-appearing watersheds were preferred by most publics. This conclusion substantiated the claim that naturalness is a desirable forest landscape characteristic (Boster and Daniel 1972). Also 2 of the treated sites studied, a conventional logging of Mahan Park near Beaver Creek and a uniform stripcut on Beaver Creek Watershed 9, were preferred by many publics over a nearly natural relict forest, despite the fact that these 2 sites were clearly distinguishable as treated. SBE is an efficient and relatively objective means of assessing the scenic beauty of forests and other wildlands and of predicting aesthetic consequences of alternative land management practices.
- Information obtained on resources in the ponderosa pine forests provided a framework for developing models to simulate the responses of natural resources to the treatments applied to the Beaver Creek watersheds. This aspect of the project resulted in a number of publications related to hydrology, vegetation, and wildlife responses (Baker 1975, Bojorquez-Tapia 1987, Brown and Daniel 1984, Ffolliott 1985, Ffolliott et al. 1988, Larson 1975, Larson et al. 1979, Li et al. 1976, O'Connell 1971, Rogers 1973, Rogers et al. 1982). A complete list of publications on modeling and simulation techniques is in Baker and Ffolliott (1998).
- Fire can be prescribed to consume portions of the forest floor, including the accumulation of dead organic material on mineral soil, and to impact the hydrologic behavior of the burned site (Ffolliott and Guertin 1990). Burning the L layer (unaltered organic material), the F layer (partly decomposed organic material), and the H layer (well-decomposed organic material) affects postfire infiltration rates and erosion potentials. Other effects of fire include thinning forest overstories from below, increasing seedling establishment and production of herbaceous plants, and temporarily reducing the fire hazard.
- Wildfire of moderate severity can have effects similar to prescribed fire. However, wildfire of high severity often results in burning the forest floor to the mineral soil and inducing a water-repellent layer in sandy soils (Campbell at el. 1977). The reduced infiltration rates can greatly increase surface runoff from the burned site, which causes soils to erode and removes nutrients that have been mineralized by the fire. All small trees and many large trees can be killed, which results in large increases in herbage production.

Conversion of pinyon-juniper woodlands to herbaceous covers by cabling, felling, and herbicide treatments (Clary et al., 1974) resulted in the following resource responses:

- Mechanical methods (cabling and felling) of pinyon-juniper removal cannot be expected to increase water yields (figure 15). However, a herbicide treatment (aerial application of picloram and 2,4-D) increased annual water yield by about 0.6 inch (Baker 1984). In this treatment, the pilot watershed was sprayed with the herbicide mixture to kill the overstory trees. These dead trees were removed after 8 yr of post-herbicide evaluation. Streamflow was reduced to near pretreatment levels after the dead trees were removed
- Cabling resulted in increased suspended sediment concentrations at specified streamflow discharges, while the herbicide treatment did not cause a change (Lopes et al. 1996). Soil disturbances during the uprooting of trees by cabling were believed responsible for the increased sediment concentration. Chemical water quality remained unchanged following conversion.
- Herbage production, generally lower in the pinyon-juniper woodlands than in the ponderosa pine forests, has increased as a result of the conversion treatments (Ffolliott and Clary 1986). The value of this increase for livestock or wildlife is temporary because it probably will decline as the pinyon-juniper overstory becomes reestablished.
- Big and small game species dependent on pinyon-juniper trees for forage and cover generally decline as a consequence of conversion treatments (Ffolliott and Clary 1986). However, cottontails can increase, provided a sufficient canopy cover remains. The numbers of overstory-dependent, non-game birds decrease after treatment and are replaced by ground-feeding species.

Figure 15. Felling treatment in pinyon-juniper vegetation type on Beaver Creek.

These results were obtained on watersheds located on volcanic soils along the Mogollon Rim. The literature suggests that similar results might be obtained on volcanic soils elsewhere in the Central Arizona Highlands. However, extrapolation of the results from Beaver Creek to sites on sedimentary soils requires prior validation (Ffolliott and Baker 1977).

Measurements continued on treated and control watersheds after the treatments were applied. Streamflow, sediment production, and water quality were monitored regularly through 1982. Other resources continue to be reinventoried periodically. Multiple-resource changes caused by management practices applied to pilot watersheds continue to be evaluated by comparing post-treatment values with pretreatment data, and with data from the untreated, control watersheds.

Implications

Similar projects included in the Arizona Watershed Program were undertaken by the USDA Forest Service in mixed conifer forests, chaparral shrublands, and streamside vegetation, as reported elsewhere in this publication. Results of studies conducted at Beaver Creek, and other research sites in the Central Arizona Highlands, have shown that:

- Changes in vegetative cover can produce short-term changes in streamflow from some vegetation types (Hibbert 1979, Baker 1984, 1986).
- Much of the additional streamflow accrues during above average precipitation years when reservoir capacity or operating strategy may not allow effective use or control of this additional runoff.
- Some vegetative modifications on upstream watersheds can be designed to increase water yields and still provide forage, wildlife, timber, and amenity values required by society in some optimal combination. This finding is not surprising as many of the management practices tested are common in principle and application to programs often used to benefit other natural resources in a ecosystem-based, multiple-use management framework.

Implications of the Beaver Creek Project and the Arizona Watershed Program as an entity are not confined to the Central Arizona Highlands or to the Southwest, but they are of national and international interest (Ffolliott and Brooks 1990, 1996). The Beaver Creek watershed continues to be frequently visited by scientists, administrators, and students from other states and countries. The results from Beaver Creek are being applied in many arid and semi-arid regions of the world.

Current Status

Most of the published and unpublished results of research conducted on the Beaver Creek Watershed between 1957 and 1982, and from more recent monitoring

activities, re-inventories of resources on the watershed, and additional analyses of the original data is in the annotated bibliography by Baker and Ffolliott (1998). The 24 subject areas contained in the bibliography and nearly 700 references cited provide insight into the breadth and diversity of research developed during the Beaver Creek Project.

Because of the unique nature and length of the data sets obtained on Beaver Creek, particularly the hydrologic data, scientists continue to analyze these data sets to meet current objectives. The Beaver Creek watershed has provided the study site and, in many instances, the Beaver Creek Project has furnished financial assistance for 49 theses and 18 dissertations on a diversity of topics. Included are 2 dissertations from Colorado State University; one dissertation from the Massachusetts Institute of Technology; one dissertation from Michigan State University; 9 theses and one dissertation from Northern Arizona University; 39 theses and 12 dissertations from the University of Arizona; and one thesis and one dissertation from Utah State University.

Because of the length of time since much of the original data were obtained (20 to 35 yr in many cases), additional, up-dated information on plant responses to the treatments is being collected by re-inventorying the original, permanently-located sampling units on the watersheds (Ffolliott and Gottfried 1991a, 1991b; Sheppard and Edminster 1997). Repeated measurement of these inventory locations provides a method of evaluating long-term changes in managed and unmanaged ponderosa pine forests and pinyon-juniper woodlands. The information obtained allows investigations of long-term ecosystem responses to disturbances including climatic change, habitat fragmentation, and invasion of exotic species.

The Beaver Creek Watershed remains a biosphere reserve and continues to function as an outdoor laboratory, providing study areas for various research cooperators. Those interested in exploring these opportunities should contact the Rocky Mountain Research Station, USDA Forest Service, Flagstaff, Arizona.

Most of the references in the annotated bibliography of publications based on the Beaver Creek Project (Baker and Ffolliott 1998) are found in the Northern Arizona University Library, Special Collections (Beaver Creek Watershed Project), other university libraries, or the Rocky Mountain Research Station field unit in Flagstaff, Arizona. Included are copies of administrative reports, hand written notes from respective scientists, maps showing location of study plots, and original records of research data. This information is invaluable for continuing long-term evaluations of climate, flora, and fauna of the ponderosa pine forests and pinyon-juniper woodlands in the Southwest.