Contributions of Silvicultural Studies at Fort Valley to Watershed Management of Arizona's Ponderosa Pine Forests

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***Abstract**—Watershed management and water yield augmentation have been important objectives for chaparral, ponderosa pine, and mixed conifer management in Arizona and New Mexico. The ponderosa pine forests and other vegetation types generally occur in relatively high precipitation zones where the potential for increased water yields is great. The ponderosa pine forests have been the subject of numerous research and management activities. Although the size, topography, and drainage patterns of the Fort Valley Experimental Forest are not conducive to watershed-scale hydrologic studies, results from Fort Valley have demonstrated the potential of silvicultural options to increase water yields. These included creating openings of different sizes, shapes, and orientations, or reducing stand densities or combinations of the two. While the importance of managing forests for water yield improvement has declined, it is still a consideration in multi-resource planning. The paper reviews silvicultural prescriptions employed on some of the major watershed research studies within the ponderosa pine forests and discusses their management implications.*

Introduction

Water yield improvement has been a historical management objective for ponderosa pine (*Pinus ponderosa*) forests in the Southwest. While its relative importance has declined in recent years as management for other ecosystem values increase, it is still an important consideration. There are two general options and combinations of these options available to modify a forest to meet watershed management goals and objectives. These options are completely or partially clearing tree overstories to create openings of different sizes, shapes, and orientations; thinning tree densities to varying intensities; and combinations of clearing and thinning treatments.

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The size of the Fort Valley Experimental Forest, its topography, and the character of the drainage network are not conducive to watershed-scale hydrologic studies. The first U.S. Forest Service watershed study was initiated at Wagon Wheel Gap in Colorado in 1909 (Bates and Henry 1928). Larger scale hydrologic studies at Fraser Experimental Forest in Colorado and Sierra Ancha Experimental Forest in Arizona (Gottfried and others 1999a) did not begin until the 1930s. The Beaver Creek watershed studies followed later in the mid 1950s (Baker and Ffolliott 1999). However, results from the long history of silvicultural studies on the Fort Valley Experimental Forest (Pearson 1950; Schubert 1974; and other researchers[1]) provided the basic foundation for prescribing water yield improvement options to test in the ponderosa pine forests on the Beaver Creek and Castle Creek watersheds (Figure 1). The four case studies presented below describe some of the silvicultural treatments imposed on these watersheds and the results and conclusions. They also suggest options available for multi-resource forest management. Further details of these and other water-yield improvement treatments based on Fort Valley silvicultural studies and the results are found in the literature that evolved from these efforts and at the website: http://ag.arizona.edu/OALS/watershed/.

Complete Clearing of Tree Overstories

The U.S. Forest Service established the Beaver Creek watersheds, about 83 km (50 miles) south of Flagstaff, to study the potential for increasing water yields from ponderosa pine forests in the Salt-Verde River Basin (Baker 1986). Paired watersheds were used to evaluate the potential for water yield augmentation. The analyses compare results from treated watersheds with conditions on untreated watersheds for the same time period. The ponderosa pine watersheds are located above 1980 m (6,500 ft) in elevation where annual precipitation averages between 508 and 635 mm (20 and 25 inches). The impacts of silvicultural treatments on herbage production and wildlife habitats were important parts of this effort. Questions about the impacts of treatments on soil physical and chemical characteristics were not addressed in these early studies.

Watershed 12 is a 172 ha (425 acres) instrumented catchment on the larger Beaver Creek watershed that was completely cleared in 1966 and 1967 to evaluate the effects of this "most drastic" silvicultural treatment on streamflow (Baker 1986). The overstory consisted of ponderosa pine and intermingling Gambel oak (*Quercus gambelii*) and alligator juniper (*Juniperus deppeana*). Once cut, the merchantable wood was removed and residual slash was piled in parallel windrows that were aligned perpendicular to the stream channel to facilitate a more direct transport of overland flow into the channel. While the original treatment prescription called for herbicide control of post-treatment Gambel oak and alligator juniper sprouts, subsequent chemical-use restrictions prevented implementation of this treatment phase.

[1] References for many of the earlier silvicultural studies at Fort Valley are found in a series of bibliographies compiled by Axelton (1967, 1974, 1977). References on ponderosa pine research in addition to the studies at Fort Valley are also listed in these bibliographies.

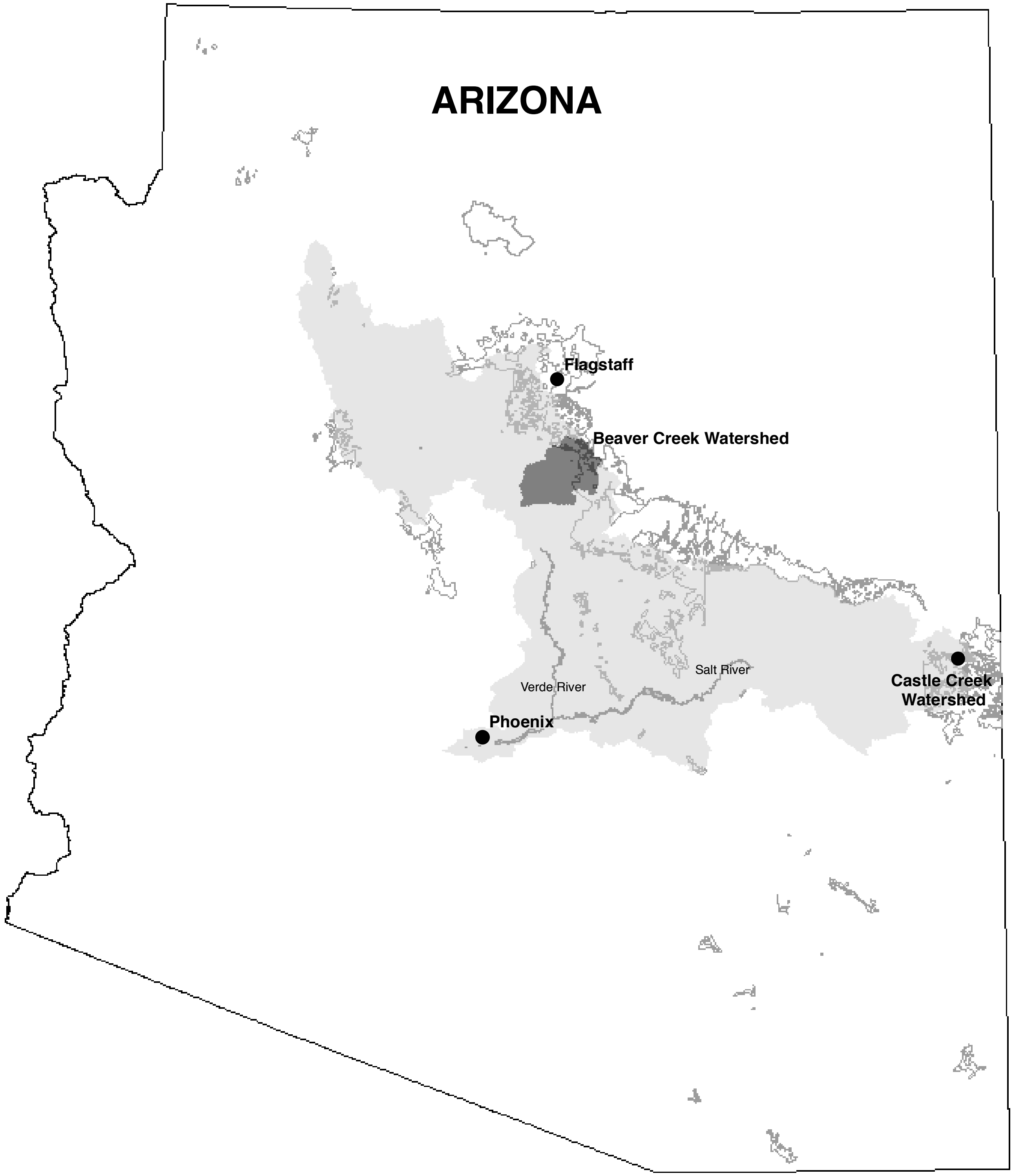

Figure 1. The major Arizona watershed study areas discussed in this paper are located within the Salt-Verde River Basin, which provides water for Phoenix and adjacent communities in the Salt River Valley. Ponderosa pine forests are located along the Mogollon Rim, on the southern Colorado Plateau, and at higher elevations throughout Arizona. The figure is adapted from Brown and others (1974).

Streamflow Response

Streamflow increased for seven years on Watershed 12 following the complete clearing of the tree overstory (Baker 1986). The average streamflow increase with the standard error was 43 ± 5 mm (1.7 ± 0.2 inches), or 29.9 ± 3.1 percent. The largest annual increase of 140 mm (5.5 inches) occurred in 1973, one of the wettest years in the region. The increase in streamflow was primarily due to the decrease in water loss by transpiration (Baker 1986; Baker and Ffolliott 1999; Brown and others 1974). More overland flow also resulted from melting snowpacks—the primary source of annual streamflow from the watershed—due to a reduction in soil moisture deficits. The windrowed slash trapped snow and delayed melt rates on the lee sides of the windrows until the ambient temperature increased enough to rapidly melt snow. As a result, more of the overland flow reached the stream channels (Baker 1983). Within seven years following the clearing treatment, vegetation recovered sufficiently so that the initial soil-water depletion was about the same as under the pre-treatment cover. Sediment yields are generally small from untreated stands on soils derived from basalt parent material. Average annual yield was about 1.3 t/ha (0.6 tons/acre) (Brown and others 1974). Sediment yield increases following the clearing treatment ranged from 0.02 to 60.5 t/ha (0.01 to 27 tons/acre). The highest value occurred immediately after treatment and probably reflects the maximum sediment loss potential from similar watersheds.

Silvicultural Impacts

The treatment removed Watershed 12 from timber production into the foreseeable future, but it could be managed for forage production, wildlife habitats, and watershed protection. Stocking by natural regeneration of ponderosa pine seedlings declined from 65 percent in the pre-treatment conditions to about 15 percent after the clearing treatment, only 5 percent of the watershed was stocked with seedlings that had germinated since the treatment (Ffolliott and Gottfried 1991). Stocking remained relatively constant for 23 years following the clearing treatment (last inventoried in 1989). At this time, it appears unlikely that the watershed could be managed for future timber production without artificial regeneration.

Gambel oak and alligator juniper sprouts were numerous and remained vigorous into the early 1990s. Silvicultural studies at Fort Valley (Schubert and others 1970, Schubert 1974) suggest that artificial regeneration of ponderosa pine must be initiated soon after clearings to minimize the problems of this competing vegetation. Artificial regeneration was not prescribed for Watershed 12. However, management goals other than "traditional timber production" are possible (Baker and Ffolliott 1999). Increases in the production of forage plants can improve the potential for livestock grazing. Baker and Ffolliott (1999) report average increases in the production of forage and non-forage understory species of about 560 kg/ha (500 lb/acre) after complete overstory removal at Beaver Creek. Untreated ponderosa pine forests in this area usually produce about 222 kg/ha (198 lb/acre) annually of grasses, forbs, half-shrubs, and shrubs (Brown and others 1974). An abundance of post-treatment Gambel oak sprouts is also beneficial to big game and other wildlife species (Ffolliott and Gottfried 1991). The clearing treatment created a more diverse landscape for wildlife by breaking up the largely continuous ponderosa pine cover in the immediate area. This landscape is more aesthetically pleasing. Gambel oak and alligator sprouts also produce firewood for local inhabitants.

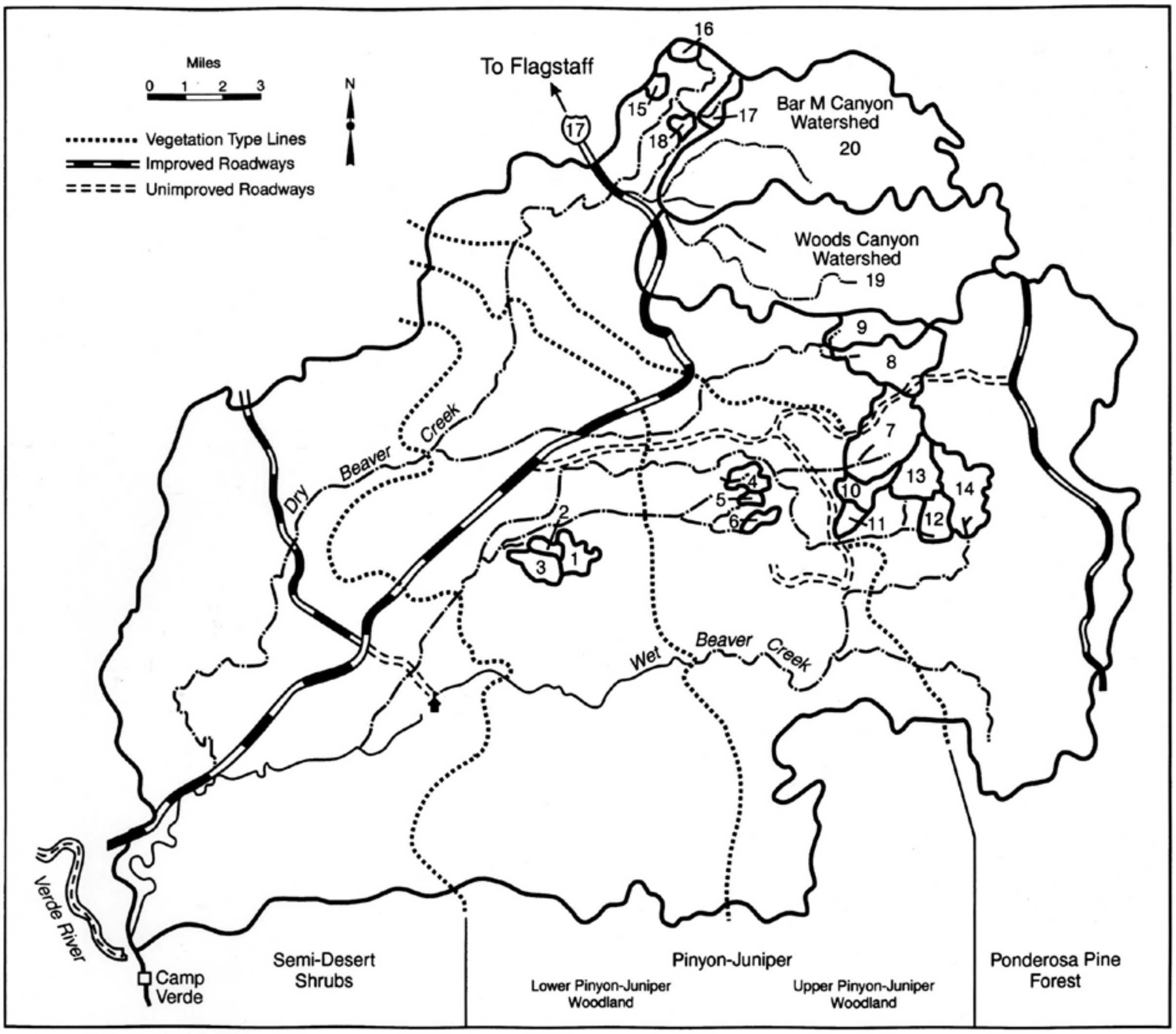

Figure 2. The Beaver Creek watershed is upstream from the junction of Beaver Creek and the Verde River. The three vegetation types found on the watershed are ponderosa pine, pinyon-juniper, and semi-desert shrubs. Twenty pilot watersheds within the Beaver Creek watershed were installed to test the effects of vegetation management practices on water yield and other resources. The figure is adapted from Baker and Ffolliott 1998.

Thinning of Tree Densities

The tree overstory on the 121 ha (298 acres) Beaver Creek Watershed 17 was commercially harvested by group selection and the remaining ponderosa pine trees were uniformly thinned in 1969. This left residual stands in even-aged groups at a basal area level of about 5.7 m^2/ha (25 ft^2/acre). While the prescribed basal area level was less than the "general guideline" for the region at the time of the treatment (Ffolliott and others 2000), it was considered above the level where excessive windthrow of residual ponderosa pine trees might occur. It was also "slightly above" the initial thinning level of 6.9 m^2/ha (30 ft^2/acre) on the Growing Stock Level plots at Taylor Woods in the Fort Valley Experimental Forest (Myers 1967; Ronco and others 1985; Schubert 1971). Growing stock levels are numerical indices defining the basal area in square feet per acre that residual stands have or will have when the average diameter, breast high (dbh), of the thinned stand is 25 cm (10 inches) or more. With the exception of den trees, Gambel oak trees larger than 38 cm (15 inches) in dbh were removed from the watershed and all alligator juniper trees were cut regardless of their size. Seventy-five percent of the original basal area was removed from the watershed leaving an average of about 4.6 m^2/ha (20 ft^2/acre) of basal area in trees 18 cm (7 inches) and larger at dbh. Slash was piled in windrows in a manner similar to the treatment on Watershed 12.

Streamflow Response

Significant streamflow increases persisted for 10 years following the thinning treatment (Baker 1986; Baker and Ffolliott 1999; Brown and others 1974). The average annual streamflow increase was 41 ± 5 mm (1.6 ± 0.2 inches) and ranged from 10 to 30 percent above the predicted streamflow if the watershed had remained untreated. The post-treatment streamflow response was considered the result of reduced transpiration losses and increased efficiency in the transport of overland flow to the stream channel. It also appeared that the residual windrowed slash influenced snowpack accumulation and melt patterns in a manner similar to that observed on Watershed 12. Annual sediment yields were between 0.07 and 0.72 t/ha (0.03 and 0.32 tons/acre) following treatment (Brown and others 1974).

Silvicultural Impacts

The treatment resulted in a large initial reduction in the number of trees, basal area, and volume per acre. However, the stand is currently recovering but the levels are still less than before the treatment. An inventory conducted 25 years after the treatment indicated that the basal area and volume of the residual trees increased on a per acre basis while the number of trees remained essentially the same (Ffolliott and others 2000). Researchers hypothesized at the time treatment was implemented that basal area and volume would continue to increase as the residual trees increased in size. The trends observed on Watershed 17 were similar to those reported in earlier thinning studies by Gaines and Kotok (1954), Myers and Martin (1963), Pearson (1950), Schubert (1974), and others. Stocking of natural regeneration was severely reduced by the treatment from over 50 percent before to less than 2 percent immediately after thinning. The initial loss in natural regeneration was temporary. Nearly 40 percent of the watershed became re-stocked with natural regeneration within 10 years of the thinning (Ffolliott and others 2000). The scarified soil surface resulting from the treatment provided a favorable bed for germination of seeds dispersed in the 1970 and 1973 seed years (1 and 3 years following the treatment, respectively). The resulting stocking level was about 15 percent higher than that observed 23 years after the trees were cleared on Watershed 12 (Ffolliott and Gottfried 1991).

While the integrity of future stands on Watershed 17 should be retained at relatively low density levels, it is unlikely that timber production can be sustained (Ffolliott and others 2000). Managing for other resource values is a more plausible scenario (Baker and Ffolliott 1999). Increases in forage production relative to pre-treatment conditions should continue into the near future. Watershed 17 produced an annual average of 112 kg/ha (100 lb/acre) of additional herbage following treatment (Brown and others 1974). Clary (1975) indicated that herbage production under thinned stands was significantly greater than under unthinned stands for given basal areas of less than 16.1 m^2/ha (70 ft^2/ acre). The habitats for many wildlife species have been enhanced largely because of the combined increased forage production and retention of protective cover.

Combined Clearing and Thinning of Tree Overstories

A combined stripcut-thinning treatment was carried out on the 546-ha (1,350-acre) Beaver Creek Watershed 14 in 1970 and 1971. Trees were cleared in alternate strips 18 m (60 ft) wide with leave strips 36 m (120 ft) wide. The stripcuts were irregularly shaped for aesthetic purposes and oriented in the general direction of the land slope. Occasional ponderosa pine and Gambel oak trees were left in the stripcuts to break up their continuity. Ponderosa pine trees in the intervening leave strips were thinned to 18.4 m^2/ha (80 ft^2/acre) by a silvicultural prescription designed to favor size classes in short-supply in the region at the time, specifically trees 30 to 61 cm (12 to 24 inches) in dbh. Thinning was based on individual groups of trees. Dominance was determined by the size class of trees with crowns occupying the greatest portion of the area. All of the trees in the non-dominant size classes were cut, with the exception of those in places where the basal area of the predominant class was less than 18.4 m^2/ha (80 ft^2/acre). Gambel oak over 38 cm (15 inches) in dbh was cut unless there was evidence of use as a den tree. All alligator juniper trees were cut regardless of size. The stripcut-thinning treatment removed about 40 percent of the basal area on the watershed. Slash was pushed to the center of the stripcuts and burned. Ponderosa pine seedlings were planted in the stripcuts on the better sites to supplement natural seedlings that survived the thinning treatment.

Streamflow Response

The thought behind the combined stripcut-thinning treatment was that streamflow would increase because water loss by transpiration would decrease and the efficiency in transporting overland flow to the stream channel would increase because of the uphill-downhill orientation of the stripcuts. Increased overland flow was anticipated because more snow would accumulate in the stripcuts due to reductions in interception losses and a re-distribution of snowfall by wind. A significant increase in streamflow was observed on the watershed, but lasted only for 4 years (Baker 1986; Baker and Ffolliott 1999; Brown and others 1974). The average annual post-treatment streamflow increase was 25 ±2 mm (1.0 ± 0.1 inches), or 12 to 24 percent. The short duration of increased streamflow was possibility due to the recovery of vegetation in the stripcuts, including planted ponderosa pine seedlings (Ffolliott and Baker 2001).

Silvicultural Impacts

The combined clearing and thinning treatment removed the tree overstory in the stripcuts and left a mosaic of even-aged stands comprised mostly of trees 20 to 46 cm (8 to 18 inches) in dbh in the leave strips. Number of trees, basal area, and volume per acre of the residual trees in the leave strip increased in the initial 25-year post-treatment evaluation period (Ffolliott and Baker 2001). This finding differed from the results of earlier ponderosa pine thinning treatments where little or no increase in basal area and volume per acre was observed, but where individual trees grew faster once released by thinning (Gaines and Kotok 1954; Krauch 1949; Myers and Martin 1963; Pearson 1950; and other scientists). Similar trends to earlier studies were also observed following the thinning treatment on Beaver Creek Watershed 17. Pearson (1950) believed that this was related to the low residual stocking and high mortality of virgin and cutover stands. A pre-treatment inventory indicated nearly 20 percent stocking of ponderosa pine seedlings on the entire Watershed 14. Stocking in the leave strips was reduced to less than 12 percent by felling and skidding trees marked for thinning. This level remained largely unchanged in the 25 years since the treatment (Ffolliott and Baker 2001). Stocking in the stripcuts immediately following thinning was unknown, although stocking of reproduction in the stripcuts that were planted with ponderosa pine seedlings was almost 45 percent in 1996.

The integrity of ponderosa pine stands in the leave strips should be maintained into the future. Growth of these stands should increase as residual trees in the leave strips increase in basal area and volume. However, management of ponderosa pine forests has changed from a timber production emphasis in the early 1970s to a more holistic perspective of natural resources management. Current forest management considers other ecosystem-based, multiple-use benefits. Increases in forage production will likely continue in the near future in both the stripcuts and leave strips and wildlife habitat should improve as a result of increases in forage production, retention of protective cover in the leave strips, and edge effect (ecotone) between the cut and leave strips.

Timber Harvesting and Thinning of Tree Overstories

The two Castle Creek watersheds in eastern Arizona, south of Alpine (Figure 1), are part of a group of ponderosa pine, mixed conifer, or mountain grassland experimental watersheds within the Apache-Sitgreaves National Forests. The Castle Creek watersheds were originally established to investigate the effects of harvesting timber in ponderosa pine forests on streamflow volumes based on the "best thinking" of U.S. Forest Service personnel at the time of treatment (Rich 1972; Rich and Thompson 1974). As part of this overall effort, a timber harvest and silvicultural treatment was applied to the 364-ha (900-acre) West Fork of Castle Creek in 1965 through 1967 to obtain timber resources and place the remaining tree overstory into the "best growing condition possible." The plan was to initiate movement of the pre-treatment uneven-aged stand structures to an even-aged system of management. The adjacent East Fork watershed was maintained as the hydrologic control.

The timber harvesting operation involved clearing one-sixth of West Fork in openings (blocks) fitted to the existing stands of over-mature and unneeded tree size-classes. The remaining five-sixths were thinned to remove poor-risk and over-mature trees, mature trees necessary to release crop trees, damaged trees, and all trees infected with dwarf mistletoe (*Arceuthobium vaginatum* var. *cryptopodum*) (Gottfried and DeBano 1990, Gottfried and others 1999b). This treatment phase "mimicked" a shelterwood system at a growing level of about 13.7 m^2/ha (60 ft^2/acre). The idea was to simulate "commercial timber management" by initiating a 120-year rotation with a 20-year cutting cycle. This management model was based on the results of earlier silvicultural studies at Fort Valley and later proposed by Schubert (1974) and others to produce the "highest possible" sustained yield of high-quality trees. About 50 percent of the original basal area of 31 m^2/ha (135 ft^2/acre) was removed by this harvesting and thinning treatment.

Streamflow Response

Increases in streamflow on West Fork remained largely stable at 13 mm (0.5 inches), or about 30 percent, for more than 20 years after implementing this treatment (Gottfried and DeBano 1990). These increases are largely attributed to reduced evapotranspiration rates and increased snowpack accumulations (Gottfried and DeBano 1990; Rich 1972; Rich and Thompson 1974). The increased streamflow was presumed a consequence of new tree roots not fully occupying the soil mantle and to the height differences between residual trees surrounding the cut openings and regeneration in these openings. This caused aerodynamic conditions that increased snowpack accumulations in the openings (Gottfried and others 1999b).

Silvicultural Impacts

The treatment on West Fork achieved the original purpose of initiating a schedule of harvesting timber and management of ponderosa pine stands in a shelterwood system with a rotation of 120 years with a 20-year re-entry cycle (Rich and Thompson 1974). The post-treatment stand structure on West Fork more closely resembled the initial stages of a balanced even-aged condition than did the pre-treatment structure. Silvicultural studies at Fort Valley indicated that a balanced even-aged stand structure has a greater timber-productivity potential than an unbalanced stand (Pearson 1950; Schubert 1974; and other scientists). However, since timber production is no longer a management emphasis in Arizona's ponderosa pine forests, the main focus at the present time is to obtain ecosystem-based, multiple use benefits (Gottfried and others 1999b). Effects of the harvesting and thinning treatment on West Fork were particularly valuable to wildlife. The mixture of forest cover and interspersed cleared blocks provided excellent habitats for big game species (Patton 1974).

Management Implications

Results from the silvicultural studies conducted at Fort Valley were important to planning treatments designed to improve water-yields in the ponderosa pine forests of the Southwest. The research provided the foundation for prescriptions that were evaluated on the experimental watersheds at Beaver Creek, Castle Creek, and on other watersheds in the state. Subsequent findings from these "watershed experiments" have become major contributions of the Arizona Watershed Program. This initiative was formed in the late 1950s by the U.S. Forest Service and its cooperators to ascertain the potentials for increasing streamflow from the upland watersheds by manipulating forest and other vegetative covers (Fox and others 2000). The studies demonstrated increased water yields when watersheds were cleared and when stand densities were reduced. Some studies such as the strip cutting and thinning on Watershed 14 and the openings and improvement harvest at Castle Creek employed a combination of strategies. Improved water yields are attributed to reductions in stand evapotranspiration or to the redistribution and differential melting of snow. All treatments were beneficial for wildlife and range resources depending on opening characteristics and degree of canopy reductions. Much of the accumulated knowledge gained in the program's 40 years provides today's managers with a better, more holistic, and perhaps, more realistic basis for management of the natural resources in Arizona's ponderosa pine forests. The case studies presented in this paper represent only a few of the contributions to watershed management from the Fort Valley silvicultural studies. Other examples are found in the literature that evolved from the watershed program.

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