*Review*

# Multi-Resource Watershed Research in the Southwestern USA and the Four Forests Restoration Initiative: A Review

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**Abstract:** Wildfires have impacted thousands of acres of forests in Arizona and New Mexico in recent years. The extensive damage has been partially attributed to the current forest condition where many once open stands now consist of dense stands of younger, unhealthy trees and buildups of forest fuels. In Arizona, land managers and community organizations developed the Four Forests Restoration Initiative (4FRI) to attempt to rectify the situation by thinning the forest while protecting wildlife and watershed resources. Integrated resource information and research are particularly important today with society's increased demands for high quality water, healthy forests, sound fire management, and viable wildlife populations. However, many managers are not familiar with previous integrated watershed research in the Southwest that could provide a strong basis for current management decisions or as a basis for future research. New and modified prescriptions to manage the Southwest's forest resources are vital to answer the threats of wildfires and insect infestations. Integrated forest resource management is necessary to meet the diverse needs of society and the land. The 4FRI plan raised many questions about the effects of silvicultural prescriptions on tree, wildlife, and water resources. The Beaver Creek, Thomas Creek, and Castle Creek watershed experiments all had goals of evaluating integrated resource management options and of providing managers and scientists with useful management information. Much of the knowledge gained in these programs can provide forest managers with a better, more holistic basis for future integrated management of the Southwest USA's forests and woodlands. This paper reviews research on three watershed areas in Arizona where integrated resource management was successful.

**Keywords:** watershed; forest restoration; integrated resource management; Southwest USA; Beaver Creek; Thomas Creek; Castle Creek

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## 1. Introduction

Integrated forest resource management should be based on a foundation of integrated forest research. Early research often tended to examine one main resource, such as timber production, without considering other forest resources such as wildlife or watershed values. Integrated research is particularly important today with society's increased demands for high quality water, healthy forests, sound fire management, and viable wildlife populations.

Research efforts in Arizona that began to be integrated started in the ponderosa pine (*Pinus ponderosa*) forests at Beaver Creek, near Flagstaff, to determine the effects of a variety of stand treatments on several forest values. Similar research was employed in the higher elevation ponderosa pine and mixed conifer forests studies of Arizona's White Mountains. Knowledge of the previous research should provide land managers and scientists with a strong basis for current management decisions or as a basis for future research. Many questions raised by current managers were answered in the past. Unfortunately, some of today's managers are not familiar with these earlier research findings and some are attempting to duplicate the research. Many of the published papers and proceedings are considered “gray literature” [1], but this should not diminish their value. A review of these experiments should be helpful to today’s managers.

Early forest managers recognized that forests produce many resource benefits, but they often concentrated on timber production and its economic benefit to local communities. In the arid Southwest, the availability of adequate water resources has been a critical concern since prehistoric times. The importance of upland watershed management increased after European-American settlers entered the Salt River Valley, which now includes the Phoenix Metropolitan Area. An agreement was reached with the Federal Government in 1904 to build the Theodore Roosevelt Dam on the Salt River to provide consistent streamflow for irrigation and domestic uses [2, 3]. The Salt River watershed contains high-elevation forests which are important sources of snowmelt and rain generated runoff for the six dams on Phoenix’s Salt River System.

Arizona and New Mexico support 2.4 million ha of ponderosa pine forests and its varieties. Conditions in high elevation southwestern ponderosa pine and mixed conifer forests have changed since European settlement. The original forest stands were relatively open with irregular, uneven-aged structure consisting of small even-aged groups varying in size up to several acres with a well-developed graminoid and forb component in the understory. Natural fires started by lightning or Native American activities were a component of this ecosystem affecting natural regeneration, forest structure and density and understory vegetation. Conditions changed over time. In recent years the forest landscape is often crowded with dense groups of smaller, unhealthy trees (Figure 1). The change has been linked to an excellent ponderosa pine seed crop in 1919 which occurred during a moist period when the range and competing vegetation had been depleted by over-grazing during World War I. A decline in timber harvesting and a lack of natural fires combined with increased wildfire suppression also contributed to the problem. A drier regional climate may have also contributed. Unfortunately, the current conditions provide fuels and fuel ladders for potential severe high-intensity wildfires.

Forest managers, community and environmental leaders recognized that the decline of forest health in the ponderosa pine forests and determined that associated environmental degradation must be corrected. There was concern that past fire exclusion had increased the likelihood of high severity wildfires that would impact the City of Flagstaff and adjacent communities. An increased potential for insect and disease outbreaks was another concern. They initiated an effort to improve forest health by a joint effort involving the concerned parties.

The Four Forest Restoration Initiative (4FRI) is an example of applying silvicultural knowledge in collaborative management of ponderosa pine forests and adjacent southwestern mixed conifer forests. In addition to the concerns about the potential for high severity wildfires and insect infestations, there were concerns about protecting sites used by two threatened species-the northern goshawk (*Accipter gentilis*) and the Mexican spotted owl (*Strix occidentalis lucida*). The Arizona Governor formed the Arizona Governor’s Forest Health Council in 2003. The efforts were hastened by the Rodeo-Chediski Wildfire in 2002 which affected 188,179 ha of forests, woodlands, and shrublands on the White Mountain Apache Nation lands and on the Apache-Sitgreaves National Forest. Another human-caused conflagration in 2011 burned 217,721 ha of forests and woodlands on the Apache-Sitgreaves National Forest. The two wildfires reinforced the need for stand restoration treatments. Foresters observed that stands that had been thinned before the fires occurred were largely left intact by the fires.

The 4FRI program was established in [4]. The vision of the initiative is to restore forest ecosystems that will support natural fires while posing little threat of the occurrence of future large and destructive wildfires. Other objectives are to provide functioning communities of native plants and animals; protect critical watershed values; and support forest industries that strengthen local economies while conserving natural resources and aesthetic values [4]. The initiative involves four national forests-the Coconino, Kaibab, Tonto, and Apache-Sitgreaves. The objective of 4FRI is to restore conditions on 0.971 million ha of ponderosa pine forests by initially treating 12,140 ha annually for 20 years.

**Figure 1.** Untreated, dense ponderosa pine stand in Arizona's White Mountains. (Photo by Gerald Gottfried, USDA Forest Service, Rocky Mountain Research Station).

The prescriptions for the Coconino and Kaibab National Forests emphasize uneven-aged management while also prescribing even-aged systems to provide variations in stand structures and species diversity [5]. The plan for the Tonto and Apache-Sitgreaves National Forests called for dwarf mistletoe (*Arceuthobium vaginatum* subsp. *cryptopodum*) control, increased growth of residual trees and improved tree-vigor and resistance to insects and diseases. Minor tree species, such as Gambel oak (*Quercus gambelii*) and quaking aspen (*Populus tremuloides*), would be retained in all forests to improve biological diversity. Tree groups selected for regeneration would be located to achieve a diverse distribution of groups. The general directives are to manage to ensure a sustainable level of nest/roost habitat distributed across the landscape [5]. Silvicultural prescriptions are designed to protect or create Protected Activity Centers (PAC's) for the two threatened bird species. Some silvicultural prescriptions include single-tree selection, thinning, and general stand improvement.

## 2. Watershed Management Research

One of the main concerns while planning 4FRI was the effects of the heavy tree removals on watershed values. Post-fire runoff and erosion are of more concern to today's watershed managers and hydrologists than increased base-flow. Arizona, New Mexico, and Mexico suffered a severe drought in the 1950's. Public and private land and water managers during that period also were concerned that the dense stands of ponderosa pine and southwestern mixed conifer forests, pinyon-juniper woodlands and chaparral vegetation were impacting runoff volumes from the region's watersheds. Fire effects were not a critical issue at that time. They formed an ad hoc watershed committee in the 1950s to address their concerns [2, 3]. Basically, it was suggested that watershed treatments in chaparral, ponderosa pine forests and mixed conifer forests had the greatest potential for increasing streamflow. However, because little information relating to potentials to increase runoff and the impacts on other forest resources was available, a research program was initiated as part of the Arizona Watershed Program. Its purpose was to evaluate the effects of applying silvicultural treatments to increase streamflow volumes from selected watersheds before implementing large-scale operations and management practices.

While water was the key issue in the 1950s, the watershed committee recognized that forests provide numerous benefits. An integrated research program was developed to evaluate the impacts of potential of watershed treatments on resource values. The Beaver Creek Watershed Program, was led by the U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station. The team was directed by a forest economist and consisted of a forester, hydrologist, landscape architect, soil scientist, computer specialist, and a range scientist. A wildlife biologist working for the Arizona Game and Fish Department was "seconded" to the team [3]. Other members were recruited from the local universities, primarily the University of Arizona and Northern Arizona University. Silviculture-watershed studies also were conducted on the Sierra Ancha Experimental Forest near Globe and in Arizona's White Mountains on the Apache-Sitgreaves National Forest.

## 3. Integrated Watershed Research Results

### *3.1 Beaver Creek-Ponderosa Pine*

Watershed research had been conducted by the USDA Forest Service on the Sierra Ancha Experimental Forest and adjacent areas since 1925 [6]. The Forest Service's Rocky Mountain Forest and Range Experiment Station and the Coconino National Forest identified the Beaver Creek Watersheds in 1957 to evaluate the effects of various land management treatments on water yields and on associated forest resources [2]. The Beaver Creek study area, 80 km south of Flagstaff, consisted of 20 gauged watersheds in the ponderosa pine forests and pinyon-juniper woodlands between 2,073 and 2,438 m in elevation. Eighteen watersheds ranged from 26.7 to 823.9 ha in size. Two larger watersheds, of 4,896 and 6,677 ha, were set aside to demonstrate the effects of operation management practices. The average annual precipitation is about 635 mm. The experimental design was based on paired watersheds where one area was treated, and an adjacent area was left as a hydrologic control. Soil surveys were conducted on most watersheds while planning treatments. The pine areas are representative of the 0.668 million ha of ponderosa pine in the Salt-Verde Watershed.

The first treatment in 1967, was a complete clearcut on one watershed (Watershed 12) to evaluate the effects of this most severe treatment on streamflow and other resources [7]. It must be emphasized that: "This was a test and not proposed as a potential management treatment." A timber harvest was conducted, and non-commercial logging slash was windrowed with rows running perpendicular to the slope. The treatment resulted in a significant increase in runoff (43 mm) because of reduced transpiration and increased snow accumulations and delayed melt behind the windrows. The Gambel oak and juniper (*Juniperus deppeana*) vegetation recovered in seven years because of sprouting but natural pine regeneration was not successful [8]. Ponderosa pine seedlings were not planted on the watershed after treatment.

Watershed 12 does not support timber production, however, the Gambel oak and juniper sprouts and the forest edge produced by the logging provide cover for deer. Cottontail rabbit populations also increased. Production of forage and non-forage understory species increased to 560.5 kg $ha^{-1}$ compared to 222.0 kg $ha^{-1}$ in the untreated ponderosa pine forest [2]. Local people utilize the small trees for firewood and Northern Arizona University students use the watershed as an outdoor laboratory. The opening is esthetically pleasing because it breaks up the region's continuous pine cover. Foliage-gleaning birds and cavity nesting birds declined while birds that scavenge for food on the ground were less affected by the treatment [9].

A treatment was conducted in 1969 on Watershed 17 [7] to determine the impacts of reducing stand densities utilizing group selection and thinning prescriptions. The objective was to leave a residual stand of even-aged groups with an al average basal area of 5.74 $m^2$ $ha^{-1}$. This density was considered sufficient to reduce windthrow but insufficient for sustained wood production. Slash was piled perpendicular to the slope as on Watershed 12. There was a significant average increase of 41 mm in streamflow. Herbaceous production increased by 112.1 kg $ha^{-1}$ and wildlife habitat improved because of the cover and increased forage production under the residual stand.

A subsequent experiment which combined clearing and thinning treatments was conducted on Watershed 14 in 1970-71 [7]. The prescription called for a strip shelterwood with 18.3 m cleared strips between 36.6 m wide areas of residual cover. The strips were irregular to provide for esthetic considerations and were oriented perpendicular to the channels. Pine stands were thinned to 18.37 $m^2$ $ha^{-1}$ with the objective of managing trees in the 30.5 to 61.0 cm diameter classes. Slash was piled and burned, and openings were planted. Annual streamflow increased by 25 mm. While timber was not the primary resource, the treatment favored wildlife because of increased forage and the residual tree cover.

Intensive multi-resource research was conducted throughout Beaver Creek to evaluate specific questions. Examples included wildlife studies which used tagged Abert's squirrels (*Sciurus abertii*) to determine movement and nest tree use [10]. Bird population densities decreased significantly when ponderosa pine was clearcut or heavily thinned from 27.55 to 5.06 $m^2$ $ha^{-1}$ [9]. However, bird populations increased as did species diversity and richness relative to untreated stands where less severe irregular strip shelterwood or improvement cutting were applied. The Beaver Creek watersheds were selected by the United Nations as a biosphere reserve.

*3.2 Castle Creek -Ponderosa Pine*

While the Beaver Creek experiments were progressing, questions were raised about the impacts of silvicultural treatments in the higher elevation ponderosa pine forests such as those found on the Apache-Sitgreaves National Forests [11]. Elevations on Castle Creek ranged from 2,388 to 2,602 m and annual precipitation averaged 686 mm between 1956 and 1987. Ponderosa pine accounted for 81% of the total basal area, the rest of the tree species, which are found at the higher elevations and along drainages, included Douglas-fir (*Pseudotsuga menziesii* var. *glauca*), ponderosa pine, Southwestern white pine (*P. strobiformis*), white fir (*Abies concolor*), and quaking aspen (Populus *tremuloides*), The West Fork of Castle Creek, with 364.2 ha, was gaged in 1955 (Figure 2) and treated [11]. The East Fork was also gaged and retained as the hydrological control. The goal was to investigate the effects of harvesting timber in the ponderosa pine forests on streamflow volumes based on the "best thinking" of Forest Service personnel at that time [12]. Based on initial results from Beaver Creek, it was decided to evaluate a treatment using a 120-rotation with one-sixth of the area harvested in each 20-year entry. The goal was to move towards even-aged system of management from the existing uneven-aged stand structure [7]. The timber harvest cleared one-sixth of West Fork in openings fitted to the existing stands of over-mature trees and unneeded tree size classes. The remaining area was thinned to remove poor-risk and over-mature trees, damaged trees and trees with dwarf mistletoe and to release crop trees. The treatment mimicked a shelterwood system at a growing stock level of 13.78 $m^2$ $ha^{-1}$.

After 20 years, the treatment resulted in an average increase of 127 mm or about 30 percent [12]. The 20-year streamflow sustained increase, which was not observed at Beaver Creek, has been related to reduced evapotranspiration rates and increased snowpack accumulations in the dispersed openings. The soils are deeper at Castle Creek than at Beaver Creek reducing potential transpiration reductions from the soil profile. Ponderosa pine seedlings were planted in some openings. It presumes that the new regeneration, with shallower root systems, was not using as much moisture as the original stand and that the height difference between the regeneration in the openings and the borders surrounding them resulted in aerodynamic conditions that favored increased snow accumulations. The treatment with interspersed clearings and forest cover was observed to be particularly valuable for wildlife.

Current thinking favors the use of prescribed fires and managed fires to reduce accumulations of forest fuels. However, there was a general lack of knowledge about the impacts of a prescribed fire on streamflow and forest conditions. In 1981, the two Castle Creek watersheds were "reversed" and 43% of the East Fork of Castle Creek was treated with a prescribed fire and the West Fork was held as the hydrologic control [12]. Post treatment inventories indicated that 13% of the total stand showed evidence of crown scorch; most of the damage was in the smaller size classes. Post-fire mortality was equivalent to 1% of the pre-burn average basal area. The prescribed fire did not significantly increase average annual or seasonal runoff volumes. It consumed surface fuels and slightly charred middle forest floor layers, but the forest floor basically remained intact influencing infiltration and evaporation. Significant changes were found for some nutrients in the streamflow, but the changes were too small to adversely affect water quality. The small effect of the treatment on water yields was attributed to the minimal fire impacts on the forest cover.

*3.3 Thomas Creek-Southwestern Mixed Conifer Forests*

Mixed conifer forests cover 0.809 million ha in Arizona, New Mexico, and Southwest Colorado. Stand composition is variable depending on ecological position in relation to elevation, moisture, and temperature. Mixed conifer forests are found on moister, cooler climates than pure ponderosa pine and on drier, warmer climates than Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*) stands.

Watershed management research in the mixed conifer forests were conducted at Workman Creek in the Sierra Ancha Experimental Forest and on several sets of paired watersheds within the Apache-Sitgreaves National Forest in eastern Arizona. Research conducted on the two Thomas Creek

**Figure 2.** One of the two Castle Creek 120-degree V-notch weirs used to measure streamflow from the harvesting study and later, from the prescribed burning experiment (Photo by Gerald Gottfried, USDA Forest Service, Rocky Mountain Research Station).

watersheds on the Alpine Ranger District are examples of integrated watershed research studies which considered hydrology, silviculture, and wildlife values [13,14].

The mixed conifer forests on the watersheds consisted of Douglas-fir, ponderosa pine, Southwestern white pine, white fir, corkbark fir, Engelmann spruce, blue spruce (*Picea pungens*), and quaking aspen. The two watersheds were gaged. The South Fork watershed consisting of 227.4 ha was treated while the North Fork watershed consisting of 189.0 ha was maintained as the hydrologic control. Elevations on South Fork range from 2,545 to 2,789 m. Average annual precipitation was about 762 mm.

A primary objective was to develop an operational resource allocation and utilization procedure which could be used to develop sound management prescriptions for a 120-year rotation period. The Thomas Sale was evaluated using an alternatives analysis that compared a timber management option, a water option, and a wildlife option against a no-treatment option [15]. Transects used to sample the forest vegetation and to survey bird species were established on both watersheds. The pretreatment stand contained 45.69 $m^2$ $ha^{-1}$ of basal area. The main species were Douglas-fir, white fir, and ponderosa pine.

In the analysis and subsequent planning, South Fork was divided into six land response units. LRU's 1 and 2 were on very steep slopes. The original plan called for them to be harvested using cable-logging techniques but the cost of transporting the equipment from the Pacific Northwest and the value of the timber did not justify the expense, and these units were not logged.

A group selection was applied to one land response unit (LRU 3) and patch clearcutting was applied to another unit (LRU 4). Areas in between clearcut patches and the less severe slopes in an adjacent unit were harvested according to an individual tree selection prescription. The objective was to harvest over-mature and poor-quality trees. The timber sale covered about 75% of the watershed. The downstream stream sections of the watershed and a wet meadow were not disturbed. A net volume of 8,023 $m^3$ was harvested. An analysis of tree growth following the harvest indicated significant growth increases in all size classes below 61.0 cm at dbh [14].

An aerial survey indicated that the harvest created 63 openings varying in size from 0.2 to 1.3 ha. A study in 9 representative openings over an eleven-year period indicated a final tally of 913 conifer seedlings and 100 aspen sprouts compared to 2,709 conifers and 384 aspen in the adjacent forest. Mean stocking was 45% [16]. The conclusion was that eight of the 9 openings had regenerated successfully. The openings had significantly higher herbage production than the forest [17].

The treatment resulted in a 34% reduction in total stand basal area and created small patch clearcuts over 18% of the watershed [13]. This produced a statistically significant increase in runoff of 43 mm or 48% over the eight-year study. Much of the increase was due to snowmelt and winter rain events. The impacts of the treatment on red squirrels (*Tamiasciurus hudsonicus*), a favored prey of the Goshawk, were documented [18]. One objective was to prevent a decline in either species caused by the harvest. The impacts of the treatments on bird species and densities were studied in some detail [19]. Bird numbers were slightly lower after the timber harvest, but the number of species increased from 28 to 35. Analysis of species by nesting and feeding guilds showed no significant differences in numbers before and after treatment.

## 4. Discussion

Silvicultural prescriptions and treatments should be based on the best research science available. However, managers have raised some questions about the effects of their prescriptions. One of the common questions concerns the effects of silvicultural treatments on runoff and other watershed attributes. A water manager from Phoenix asked a colleague why the Forest Service never studied watershed management. The Forest Service person was astonished and replied that Forest Service research had been studying the effects of land management treatments on runoff since at least the mid-1920s.The problem is that much of this research had been reported in Forest Service research and conference papers and technical reports as well as outside scientific publications. Many of the modern electronic bibliographies do not contain Government publications and these articles are missed during standard library searches. These publications are often considered "gray literature," by many authors [1]. However, they indicate that Government publications can meet BASI (best available science information) standards of accurate and reliable information. Forest Service manuscripts passed technical peer reviews and statistical reviews before publication. BASI is intended to provide a base for well-informed decision making. One reason for the missing articles is that in earlier times Forest Service scientists were encouraged to publish their research in the Forest Service outlets because there were not as many journals as today that would print natural resource articles. Status of knowledge publications would be released occasional to summarize recent research findings. For example, information was presented about watershed management in Arizona's mixed conifer forests [20]. Another report was prepared by the Rocky Mountain Research Station (RMRS-GTR-13): "Multiple Resource Evaluations on the Beaver Creek Watershed: An Annotated Bibliography (1956-1996) [2]. This publication summarized 683 publications that were based on research at Beaver Creek alone. It covered 24 topics from climate and economics to wood products use.

Current thinking favors the use of prescribed fires and managed fires to reduce accumulations of forest fuels. However, there was a general lack of knowledge about the impacts of a prescribed fire on streamflow and forest conditions. The Castle Creek prescribed burning experiments would provide helpful information. How many managers are aware of this experiment and the fire's effects on the ponderosa pine watershed? The prescribed fire only resulted in relatively minor damage to the stand and did not significantly increase average annual or seasonal runoff volumes. The forest floor basically remained intact influencing infiltration and evaporation. Changes were found for some nutrients in streamflow following the treatment, but the changes were too small to adversely affect water quality.

**5. Conclusions**

The review of the silvicultural and watershed research findings from Beaver Creek, Castle Creek, and Thomas Creek should provide managers with an understanding of the effects of restoration treatments on streamflow volumes. We cannot prepare a relatively simple statistical relationship among the three because of differences in stand composition and densities, soils and geology, elevations, precipitation characteristics, and management histories. Although Beaver Creek and Castle Creek support ponderosa pine, the sites are sufficiently different to require independent experiments and analyses. The common thread for all three areas is that reducing stand densities and creating independent openings over larges areas of a landscape, whether as strip cuts or overstory removals based on stand characteristics, will increases streamflow volumes. Streamflow increases related to restoration treatments are, of cause, influenced by precipitation amounts and timing. Treatments will have less of an effect in a dry year than in a very wet year. The experiments were designed as multiple resource efforts and provided as large amount of information about silvicultural responses and bird and small mammal populations in ponderosa pine and mixed conifer habitats. The prescribed burn at Castle Creek, which is like many 4FRI prescriptions, did not affect runoff volumes because so little of the forest cover was burned. Even the loss of the top layers of the forest floor did not have an effect since the lower layers were still intact.

Management and knowledge of forest lands and their ecology requires a large amount of information. Although scientists and practitioners have been studying issues related to forests for more than a century, much still needs to be learned. Integrated resource management research is necessary to address traditional issues related to silvicultural prescriptions, but also newer issues related to changing climates, for example, success of tree regeneration, increased fire and insect management problems. The importance of integrated resource management information is apparent in numerous watershed research studies conducted in the Southwest since the middle of the last century. The scientists attempted to study the impacts of treatments on as many resources as possible within the limits of finances or the availability of scientists. The Beaver Creek, Thomas Creek, and Castle Creek watershed experiments all had a goal of evaluating integrated resource management options and of providing managers and scientists with useful information.

It is unfortunate when previous information that could be useful to current efforts is ignored because people are not aware of their existence. Forest Service scientists have been studying many of the issues related to watershed and forest management and to integrated resource management and have presented their results in publications and National Environmental Protection Agency documents. Unfortunately, many of the newer scientists and managers are not familiar with these documents. In some situations, new experiments are being designed to answer questions that were addressed in the past; this is a waste of time and funding. The lack of knowledge about the intensive watershed management research at Beaver Creek is an excellent example. Forest managers and scientists should be encouraged to review the older publications, even if they are considered gray literature, to find information that could serve as a foundation for new research. Much of the knowledge gained in these programs can provide forest managers with a better, more holistic basis for future integrated management of the Southwest's forests and woodlands.

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