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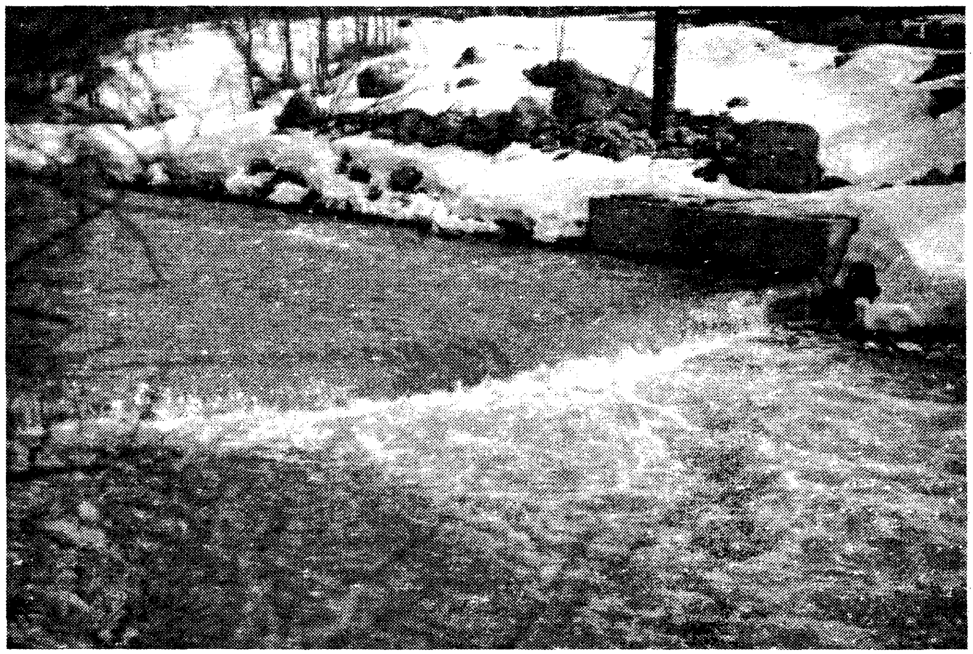
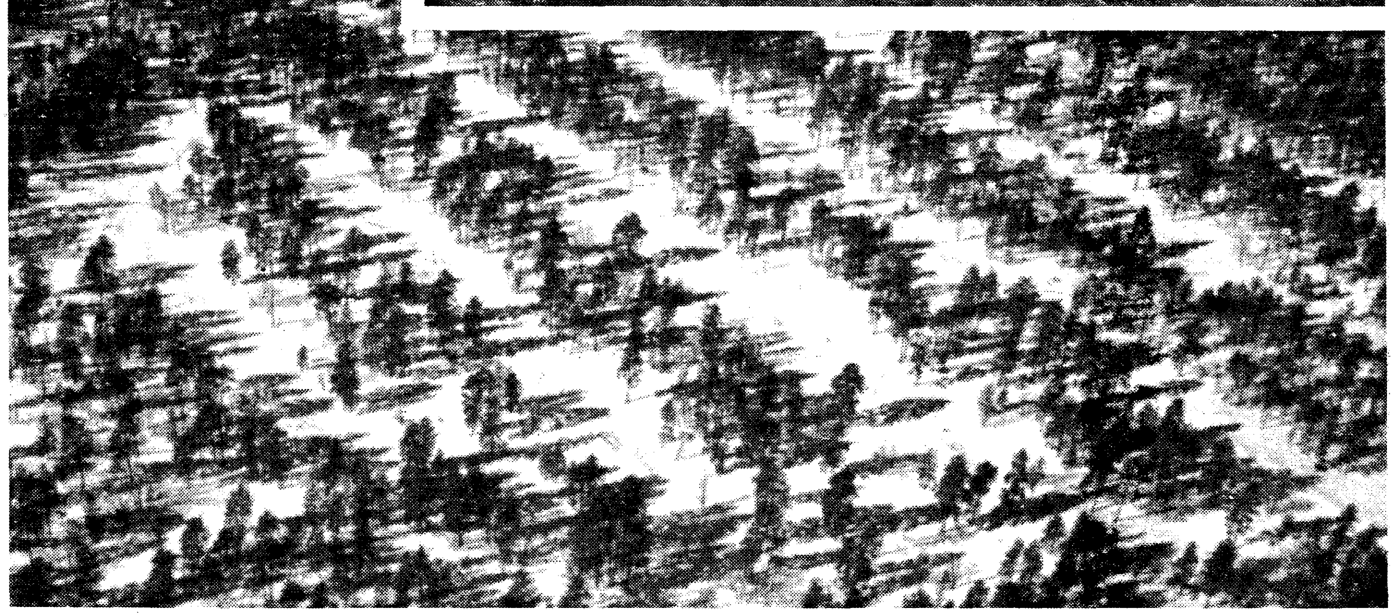
# Multiple Resource Evaluations on the Beaver Creek Watershed:
## An Annotated Bibliography (1956–1996)

**Malchus B. Baker Jr. and Peter F. Ffolliot**





# Abstract

Baker, M.B. Jr. and Ffolliott, P.F. 1998. Multiple resource evaluations on the Beaver Creek watershed: An Annotated Bibliography (1956-1996). Gen. Tech. Rep. RMRS-GTR-13. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 69 p.

The Beaver Creek experimental watershed, located in north-central Arizona, was established in 1956 in response to public concerns 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 and pinyon-juniper trees. Natural resource responses to the manipulation of ponderosa pine forests by various silvicultural treatments and by conversion techniques of pinyon-juniper woodlands to herbaceous covers were determined. Results of studies have shown that changes in vegetation cover can produce short-term changes in streamflow from the ponderosa pine type and limited amounts from a herbicide treatment of pinyon-juniper. Vegetation modifications on upstream watersheds can be designed to provide forage, wildlife, timber, and amenity values required by society in some optimal combination. The implications of results from the Beaver Creek watershed studies are not confined to the Southwest, but are of national and international interest. The history of research and watershed description are provided along with a complete listing of scientific publications relating to the Beaver Creek Watershed.

Keywords: Arizona, ponderosa pine, pinyon-juniper woodlands, semi-arid watersheds, watershed management, water yield

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**This bibliography is dedicated to Dr. Kel M. Fox in memory of his lifelong commitment to watershed management in the State of Arizona.**

*Front Cover: One objective of the Beaver Creek Project was to determine potential water yield response to manipulation of the ponderosa pine and pinyon-juniper vegetation.*

# Multiple Resource Evaluations On The Beaver Creek Watershed: An Annotated Bibliography (1956-1996)

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

## Contents

# Introduction

In 1904, the Salt River Water Users' Association signed an agreement with the United States government under the National Reclamation Act to build a dam on the Salt River below the confluence with Tonto Creek. The Roosevelt or Theodore Roosevelt Dam, the first of six dams on the Salt and Verde Rivers, was completed in 1911 and the Salt River Project was established. During the mid-1950s, the amount of water stored in project lakes was very low and, as a consequence, apprehension arose among some residents that a serious water shortage impended. Groundwater supplies in the Salt River valley were also being rapidly depleted, and pumping costs were rising steadily.

Long-term studies at Sierra Ancha Experimental Forest in central Arizona showed some potential for increasing runoff by converting brushlands to grass. Based on this, a belief existed that water yield from the Salt and Verde Watersheds could be significantly increased by treatment of various vegetation types. Suggestions for water-yield improvement included widespread burning of chaparral, eradication of pinyon-juniper by burning and mechanical methods, and prescribed burning in ponderosa pine.

In the summer of 1955, several ranchers met with a USDA Forest Service representative and an official with the Salt River Project on the Beaver Creek watershed near Flagstaff. These people were concerned that increasing densities of trees and shrubs on upland watersheds on the Salt and Verde River basins were reducing the flow of streams and the supply of livestock forage. As a result of this meeting, the University of Arizona was commissioned to investigate the potential for increasing water yield from the state's forests and ranges. The somewhat optimistic university findings, titled Recovering rainfall (Barr 1956) and better known as the Barr Report, suggested that surface-water runoff from mountain watersheds might be increased by replacing high water-using plants, such as trees and shrubs, with low water users such as grass. This 1956 report resulted in demand for an immediate action program.

In responding to this demand, the Arizona Water Program of the USDA Forest Service was initiated in the late 1950s to evaluate the usefulness of selected vegetative management programs in increasing water yields and other multiple resource benefits in the Salt River Basin (Arizona State Land Department 1962). Many questions regarding the effects of such a program remained unanswered and, the effectiveness of most of the practices proposed were untested. The Beaver Creek watershed became a significant component of the Arizona Water Program.

## Beaver Creek Watershed

The Beaver Creek watershed is between latitudes 34° 30' and 35° north, and 111° 30' to 112° west longitude in north-central Arizona. The center of the watershed is about 50 mi south of Flagstaff, Arizona, in Coconino and Yavapai Counties. The general orientation of the drainage is southwest, with the major drainage flowing into the Verde River. Interstate Highway I-17 crosses the area, linking Flagstaff and Phoenix, Arizona. This watershed was selected for research because it is representative of extensive areas of ponderosa pine forests and pinyon-juniper woodlands in Arizona and the Southwest.

The Beaver Creek watershed, encompassing 275,000 acres upstream from the junction of Beaver Creek and the Verde River (figure 1), is part of the Salt-Verde River Basins, which are major river drainages 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 watershed includes plateaus, sloping mesas and breaks, and steep canyons. Bedrock underlying the area consists of igneous rocks of volcanic origin; below these are sedimentary rocks of Kaibab, Coconino, and Supai formations (Brown et al. 1974). Elevations range from 3,000 to 8,000 ft above sea level.

Annual precipitation on the Beaver Creek watershed varies greatly from year to year, which is characteristic of the climate in the Southwest (Baker 1982). On the average, the ponderosa pine forests receive 20 to 25 inches of water / year from rain and snowfall and the pinyon-juniper woodlands receive 18 to 20 inches / year. Most of the annual runoff (95% in the ponderosa pine forest and 85% in the pinyon-juniper woodlands) is from the melting snowpack, which occurs largely in March and April.

In descending order with respect to elevation, the three vegetation types found on the watershed are: ponderosa pine, pinyon-juniper (including alligator juniper and Utah juniper subtypes), and semi-desert shrubs (figure 1). Ponderosa pine forest, characteristic of 11 million acre in the Southwest, dominate the hillsides and plateau above 6,500 ft (Brown et al. 1974). Scattered throughout the ponderosa pine forests are clumps of Gambel oak, which is the predominant deciduous tree on Beaver Creek. This oak species is a valuable source of food and shelter to wildlife. Woodlands of intermingled pinyon, Utah juniper, and alligator juniper grow between 4,500 and 6,500 ft, as they do on some 51 million acre in the Southwest (Clary et al. 1974). Representative plants (scientific and common names) by vegetation type are in Appendix A.

Habitat for many game and nongame wildlife species, is found within the Beaver Creek watershed (Ffolliott 1990, Patton 1991). Songbirds, birds of prey, vultures, and numerous small animals, such as squirrels and rabbits, are abundant. Beaver frequent the streams at lower elevations; bear is occasionally sighted in the ponderosa pine forest; and mountain lions and bobcats prowl the rocky canyons. Deer, elk, and turkeys are the major big game species on the watershed. Deer occur at all elevations in summer, while elk prefer the higher forests. When winter snows come, both deer and elk move to lower elevations. Turkeys stay in the ponderosa pine forest all year. Represen-

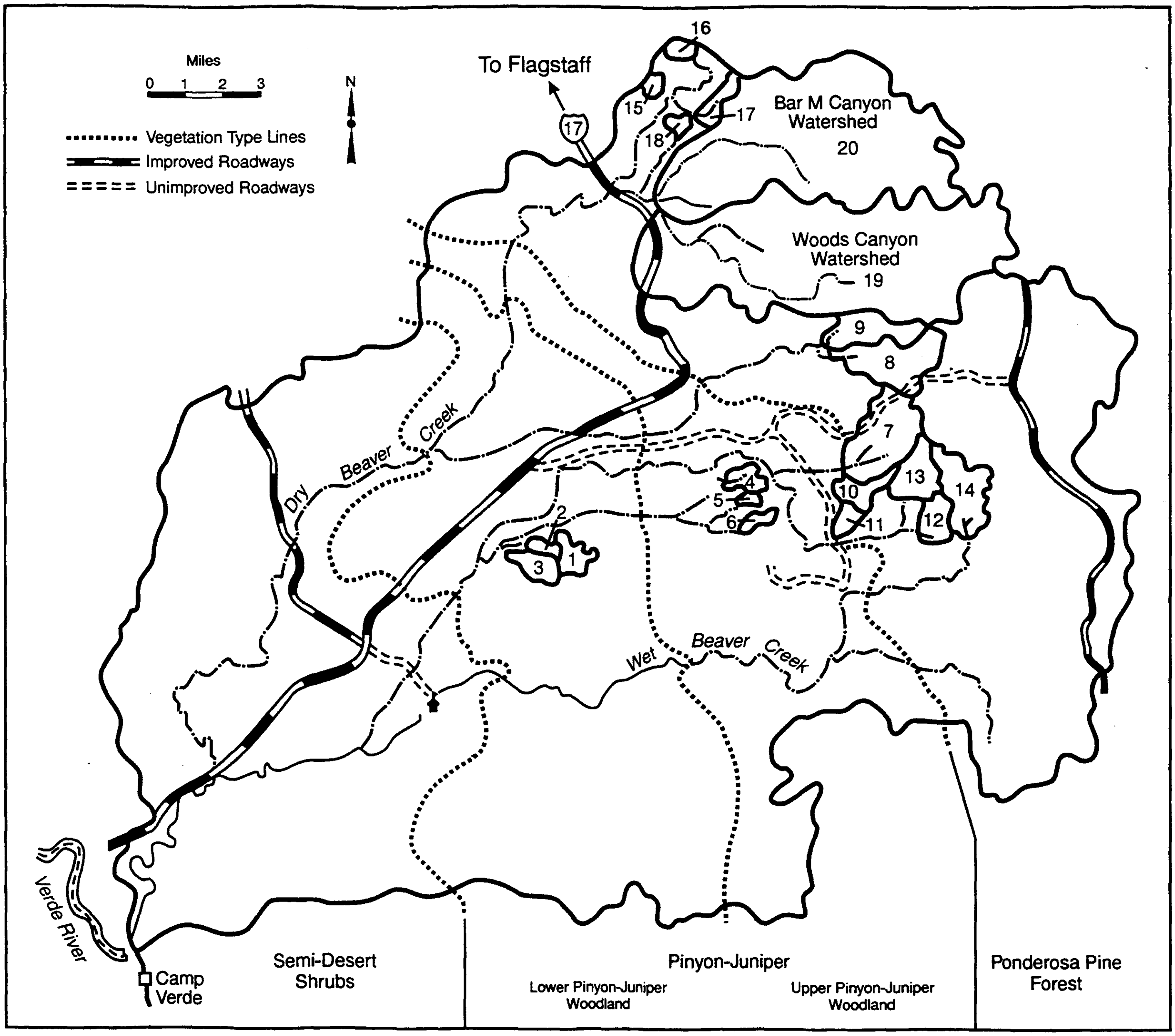


Figure 1. The Beaver Creek watershed is upstream from the junction of Beaver Creek and the Verde River. The 3 vegetation types found on the watershed are ponderosa pine, pinyon-juniper, and semi-desert shrubs. Twenty pilot watersheds within the Beaver Creek watershed were installed to test the effects of vegetation management practices on water yield and other resources.

tative fauna (scientific and common names) by vegetation type are in Appendix B.

Humans have modified the watershed areas to various degrees since the late 19th century. The earliest type of modification was the introduction of domestic livestock. Most of the ponderosa pine area has also been logged, which has changed the size and age class distribution of the trees but has not caused major ecosystem changes. Protection from naturally occurring fire since the early 1900s has had a slow, but cumulative effect.

To improve range and water yield, approximately 40,750 acre of pinyon-juniper woodlands (both alligator and Utah juniper) were converted in the early 1960s. Conversion was accomplished by uprooting trees with a cable or heavy chain pulled between two crawler tractors (chaining) or by pushing trees out of the ground with the blade of a crawler tractor (pushing). In addition, the watersheds have been altered for management purposes by constructing roads and fences and developing watering sites. At the lower end of the watershed, near the Verde River, several small residential communities have developed, while summer home developments are located on isolated parcels at high elevations (e.g., Stoneman Lake).

## Beaver Creek Project Design

Before the Beaver Creek Project was initiated, both research and management personnel of the USDA Forest Service examined the Beaver Creek site as a possible testing area. Following this examination, the inspection team recommended Beaver Creek to be a designated testing area. The Regional office of Region 3 having the administrative responsibility assumed everything was ready to start treatment. The plan, in the Region's mind at the time, was to treat the entire Beaver Creek watershed according to recommendations in the Barr Report and see what would happen. But, the Rocky Mountain Forest and Range Experiment Station scientists, who were involved in an advisory capacity, realized treating the whole area was not an adequate choice. After much discussion, it was decided that the area should be stratified, because the effects of the proposed treatments in the different vegetative types might vary considerably. Thus the Beaver Creek Project was established.

Beginning in 1957 and continuing until 1983, various vegetative manipulations, all designed initially to favor increased water yields, were applied to gauged watersheds in both the pinyon-juniper woodlands and ponderosa pine forests on Beaver Creek, and then monitored to evaluate the treatment effects on water yields and other multiple use values. Monitoring responsibilities fell largely to the Rocky Mountain Forest and Range Experiment Station, which had assembled an evaluation team of water, timber, and range specialists for this purpose, and to personnel from the Coconino Nation Forest, the area on which Beaver Creek was located.

The initial charge presented to the evaluation team was to monitor and evaluate the effects of the water yield improvement treatments to be implemented on the gauged watersheds in terms of subsequent yields of water, timber, and herbage. The role of the research evaluation team changed somewhat in the late 1960s, however. In addition to monitoring and evaluating treatment effects, the team also became more active in helping the Coconino personnel in designing the water yield improvement experiments themselves. This partnership remained in effect through the duration of the subsequent treatments on Beaver Creek

The system of paired pilot watersheds established were grouped within single vegetation types and received a single treatment at any given time for evaluation. Initial comparisons (pretreatment) of the water yield and other products from these small natural watersheds were completed before any treatments were applied. One of the pair was then altered and the other held in its original condition as a control for evaluation of change (posttreatment). Between 1957 and 1962, 20 pilot watersheds within the Beaver Creek watershed (Brown et al. 1974, Clary et al. 1974) were installed to test treatment effects (figure 1). Of the 20 watersheds, 18 were from 66 to 2,036 acre in size. The other 2 basins, encompassing 12,100 and 16,500 acre, were set aside to demonstrate the effects of management practices on areas of the size forest managers work with daily. In the early 1970s, 24 subwatersheds (10 to 100 acre in size), each having more uniform soil, plant life, and topography, were delineated in areas of diverse ecological characteristics. Seventeen of these subwatersheds were located on the Beaver Creek watershed. Information from these subwatersheds helped refine and verify findings from studies on the pilot watersheds and for application to a wider range of conditions.

Studies in ponderosa pine forests and pinyon-juniper woodlands had evolved from primarily an evaluation of changes in water yield by the late 1960s. The new emphasis was not only to determine how much water yield could be increased, but also to evaluate changes in livestock forage, timber production, wildlife habitats, recreational values, and soil movement.

Knowledge of the production relationships between the various land products is required for effective multiple-use planning. Since cattle production was an integral part of the Beaver Creek Project, an area of approximately 1,300 acre of ponderosa pine-bunchgrass range on the Wild Bill Cattle Allotment of the Coconino National Forest was used to evaluate the relationship between cattle production and overstory density (Pearson 1972). The specific objectives of this evaluation were to determine the effects of various tree overstories on quantity, quality, and composition of forage, and the relationship between beef and timber production at various tree overstory densities. Information from this evaluation was used to estimate changes in beef production following various land treatments applied on the Beaver Creek watershed. This aspect of the project resulted in a number of publications related to forage digestibility, plant phenology, and beef-forage-timber relationships (Clary et al. 1975, Pearson 1972, 1973, Pearson et al. 1972).

A wide range of forest management treatments were investigated on Beaver Creek (Brown et al. 1974, Clary et al. 1974). These management treatments included type conversion in the woodland vegetation and clearcutting, severe thinning, strip cutting, patch cutting to favor wildlife, and shelterwood cutting in the ponderosa pine type to promote maximum sustained timber production. Impacts of the treatments were measured on a wide range of ecosystem parameters including hydrologic response, timber and forage yields, soil erosion and sediment production water quality, scenic beauty, and the dynamics of insect, bird, small animals and big game populations. Much of the early research was summarized in 2 status of knowledge publications (Brown et al. 1974, Clary et al. 1974).

Ecosystem simulation models were designed, developed, and tested for use by forest managers in estimating commodity production and evaluating the impacts of alternative forest and natural resource management problems on the ecosystem. The models were designed to have broad application to forest and rangelands. Some models apply only to areas similar to those found in the southwestern United States, while others are applicable to comparable areas throughout the world.

## Biosphere Reserve

In 1976, the Beaver Creek watershed was designated a biosphere reserve. A biosphere reserve is a component of a worldwide network in Unesco's Man and the Biosphere (MAB) Program. Subsequently, the governors of Arizona and the State of Durango, Mexico, signed an agreement, titled "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 La Michilia Biosphere Reserve in Durango and the Beaver Creek Biosphere, were selected as the primary study areas for this binational program.

Although both study areas contained dry forests and woodlands, La Michilia and the Beaver Creek watershed were distinct from one another. 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 had become 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.

The objectives of this binational 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.
- Determine the habitat requirements and the distribution of preferred habitats for indigenous wildlife species and cattle, considering 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, providing a basis to identify improved methods for sustainable multiple resource management and environmental preservation.
- Produce a computerized data management system to assist decisionmakers and managers in achieving wise use and conservation of all natural resources.

Publications resulting from this binational program and others focusing on the Beaver Creek watershed as a biosphere reserve are reported in a Department of State publication in which MAB-sponsored research in the temperate regions of the world were reviewed (Ffolliott and Bartlett 1991) and are also contained within this annotated bibliography.

## Cooperation

As explained, the objective of the Beaver Creek Project developed into evaluation of the effects of vegetative treatments on all natural resource products and uses of National Forest lands, rather than on water yield alone. Therefore, the cooperation of many groups and agencies was enlisted. The U.S. Geological Survey installed and read certain stream gauges; the Arizona Game and Fish Department evaluated the effect of treatments on wildlife and habitat; research by universities complimented the efforts of the USDA Forest Service Rocky Mountain Forest and Range Experiment Station. In addition, the advice and support of other interests groups, including the Salt River Project, the Soil Conservation Districts, cattlegrowers, lumbermen, and others was available.

One of the most important interest group was the Arizona Water Resources Committee (AWRC), a committee that included civic minded, thoughtful representatives of practically every group interested in public land management. This group worked closely with the Supervisor of the Coconino National Forest, the Regional Forester of Forest Service Region 3, and the Director of the Rocky Mountain Forest and Range Experiment Station in an advisory and supporting capacity. The AWRC also played an important role in obtaining funding for much of the work accomplished by the Beaver Creek Project.

As previously stated, soon after the inception of the Beaver Creek Project, it was apparent that sophisticated evaluation techniques were required and, as a consequence, the services of USDA Forest Service Research was increased. In 1960, a staff of forest, range, and watershed scientists, economists, and hydrologists were assigned full time to the project. This team of scientists from the Rocky Mountain Forest and Range Experiment Station designed the necessary research studies and treatments, and collected and analyzed data before and after treatment.

The Beaver Creek watershed, part of the Coconino National Forest, is administered and managed by the Forest Supervisor and District Rangers. National forest personnel installed the many measuring structures and devices required, carried out the land treatment prescriptions, and performed protection and management functions. Close cooperation between administrative and research activities was required at all times.

## Results

Measurements continued on treated and control watersheds after the treatments were applied (Baker 1984, 1986, Brown et al. 1974, Clary et al. 1974). Streamflow, sediment production, and water quality were monitored regularly, and other resources were inventoried periodically. Changes caused by management practices applied to the treated watersheds were evaluated by comparing post-treatment values with pretreatment data, and with data from the control watersheds. All water-oriented studies were terminated by 1982, and final results of the initial treatment studies were reported on during the latter part of the 1980s.

Because of the unique nature and length of the data sets obtained on the Beaver Creek watershed, particularly the hydrologic data, students and scientists continue to analyze these data using new and improved techniques and modeling procedures. In addition, because it has been 20 to 30 years since many of the original data sets were obtained, new information (e.g., plant responses to the treatments over time) is being collected by inventorying the original sample points.

Results from studies on the Beaver Creek watershed have provided data for 49 theses and 18 dissertations from various universities. These include 2 dissertations from Colorado State University; 1 dissertation from the Massachusetts Institute of Technology; 1 dissertation from Michigan State University; 9 theses and 1 dissertation from Northern Arizona University; 39 theses and 12 dissertations from the University of Arizona; and 1 thesis and dissertation from Utah State University.

Similar projects included in the Arizona Watershed Program were also undertaken by USDA Forest Service units in mixed conifer forests (Rich and Thompson 1974), chaparral (Hibbert et al. 1974), and streamside (riparian) vegetation elsewhere in Arizona (Horton and Campbell 1974). Results of studies conducted at Beaver Creek (cited and annotated below), and other locations, showed that changes in plant cover could produce changes in streamflow from some by not all vegetation types (Baker 1984, 1986, Hibbert 1979).

The implications of the Beaver Creek Project and the Arizona Watershed Program are of national and international interest (Ffolliott and Brooks 1990, 1996). The Beaver Creek watershed continues to be visited by out-of-state and international students, scientists, and administrators. Research results from the project continue to find application in many arid and semi-arid regions of the world, and provide long-term resource data for new analysis techniques and model application, as indicated by the 70 publications produced since 1990.

### Current Status

The Beaver Creek watershed remains a designated biosphere reserve functioning as an outdoor laboratory providing study areas for research cooperators. Those interested in exploring research opportunities on Beaver Creek should contact the Supervisor's Office of the Coconino National Forest, Flagstaff, Arizona, for more information (520-527-3600, FAX: 520-527-3620).

The references in this annotated bibliography can be found at various locations. Journal articles can be obtained through university and public libraries. Theses and dissertations can be obtained from the cited universities or from the University of Michigan, 300 North Zeeb Road, Ann Arbor, MI, USA, 48106-1346; telephone number 800-521-3042 or 734-761-4700, extension 3766; fax, 734-973-7007. Proceedings of symposiums published by the USDA Forest Service can be obtained from the USDA Forest Service Library in Ft. Collins, Colorado (240 W. Prospect Rd, Fort Collins, CO 80526-2098) or in Flagstaff, Arizona (Southwest Forest Research Complex, 2500 S. Pine Knoll Dr., Flagstaff, AZ 86001). The Rocky Mountain Research Station Library is a member of the FS INFO Network, an Agency-wide network of libraries featuring a computer-based online bibliographic file. The FS INFO Network of Libraries not only provide traditional library and information services, but also supports other bibliographic activities in the Forest Service. The Library can supply instructions for access and users' guides. Unpublished reports can be accessed through the Northern Arizona University Library, Special Collections (Beaver Creek Watershed Project), Flagstaff, Arizona, or at the Rocky Mountain Research Station field unit in Flagstaff, Arizona. In addition to the references, administrative reports, hand written notes from respective scientists, maps showing location of study plots on the Beaver Creek watershed, and original records of research data are accessible. This type of information is invaluable for conducting long-term evaluations of climate, flora, and fauna of the pinyon-juniper and ponderosa pine types of the Southwest.

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# Annotated Bibliography

This bibliography is a compilation of most of the published and unpublished research results conducted on the Beaver Creek watershed between 1957 and 1982, studies through 1996 that used original data from the watershed, and recent monitoring activities and resource inventories on the watershed. Only original research performed or coordinated by personnel working directly on the project or for work funded through the project are included. Results from studies performed since the project terminated in 1982 are not financially supported by the USDA Forest Service, but they are included to show their value. Much of our current knowledge of water-yield improvement through vegetation manipulation of pinyon-juniper and ponderosa pine in the Southwest, and its influence on other natural resources is from work performed by Beaver Creek Watershed Project personnel or by cooperators funded through the project. Since project termination, most studies have been supported by external financial resources.

The 24 subject areas contained in the annotated bibliography and the nearly 700 references cited provide insight into the breadth and diversity of research developed through the Beaver Creek Project.

## Climate

**1. Beschta, R. L. 1974. Climatology of the ponderosa pine type in central Arizona. Arizona Agricultural Experiment Station, Technical Bulletin 228.**

Temperature, precipitation, snowfall, wind, solar radiation, cloud cover, relative humidity and dewpoint, and evapotranspiration are presented. Long-term temperature and precipitation regimes are discussed in relation to climatic trends.

**2. Campbell, R.E.; Ryan, M.G. 1982. Precipitation and temperature characteristics of forested watersheds in central Arizona. USDA Forest Service, General Technical Report RM-93.**

Precipitation and temperature characteristics of the woodland and ponderosa pine forest types are described using 23 years of record. Climatic patterns are quite representative of similar vegetation types in Arizona and New Mexico.

**3. Campbell, R.E.; Stevenson, O.G. 1977. Solar radiation measurement in northern Arizona. USDA Forest Service, Research Note RM-339.**

Mean radiation was 67% of extra-terrestrial value. January mean radiation was 272 langleys/day, while the June mean was 736. Measure of transmissivity is related to hours of sunshine, but the relation is not close enough for precise daily predictions.

**4. McAda, D.P. 1978. Indexing solar radiation by clouds for snowmelt modeling. MS Thesis, University of Arizona, Tucson, Arizona.**

Solar radiation is indexed by opaque and transparent cloud-cover characteristics determined by time-lapse photography. Index values obtained are useful in snowmelt modeling procedures.

**5. McAda, D.P.; Ffolliott, P.F. 1978. Solar radiation as indexed by clouds for snowmelt modeling. Hydrology and Water Resources in Arizona and the Southwest 8:175–181.**

Empirical relationships between commonly obtained cloud-cover characteristics and solar radiation components required in snowmelt modeling are presented. Direct and diffuse solar radiation components are related to coverage of cumulus and stratocumulus clouds.

**6. McAda, D.P.; Ffolliott, P.F. 1987. Predicting solar radiation from cloud cover for snowmelt modeling. Hydrology and Water Resources in Arizona and the Southwest 17:29–34.**

Empirical equations relating solar radiation to opaque and transparent cloud cover are incorporated into a computer subroutine for predicting solar radiation. Development of these equations is described.

**7. Solomon, R.M.; Ffolliott, P.F.; Thompson, J.R. 1976. Correlation between transmissivity and basal area in Arizona ponderosa pine forests. USDA Forest Service, Research Paper RM-318.**

Transmissivity, which is solar insolation transmitted through the forest overstory, was empirically related to stand basal area of sample plots by a logarithmic transformation. Seasonal variation was not statistically significant.

## Economics

**8. Ayer, H.W. 1977. The affects of land use policy on employment. Western Wire 2(3):2–3.**

Employment impacts are examined in several respects to determine distribution of employment by skill level; affects on neighboring economies from a single, regionwide land-use policy; changes in impacts over varying time periods; and patterns of seasonal employment.

**9. Ayer, H.W.; Baskett, J. 1978. Elasticities: Supplementary statistics from interindustry studies. Western Journal of Agricultural Economics July 1978:75–79.**

Elasticities are developed to incorporate a sector's multiplier impact and its initial relative size to provide a better estimator of the sector's importance to a region's economy. A current, empirical example of the difference between multipliers and elasticities, and their use in policy is presented.

**10. Baskett, J. 1976. Economic impacts of United States Forest Service policies on local communities: An interindustry analysis of the Salt-Verde Basin, Arizona. PhD Dissertation, University of Arizona, Tucson, Arizona.**

The general objective of this study was to evaluate the impacts of policy-sensitive sectors on employment in local areas of the Salt-Verde Basin. Specifically, estimates of the direct and indirect impacts on employment in local

areas caused by policies that affect timber cut, grazing, recreation, and retirement settlement were evaluated.

**11. Boster, R.S. 1971. The value of primary versus secondary data in interindustry analysis in Arizona. PhD Dissertation, University of Arizona, Tucson, Arizona.**

An attempt to assess the value of primary versus secondary data in view of the wide variation in collection costs is presented. Results cast doubt on the commonly held assumption of primary data supremacy in regional interindustry studies.

**12. Boster, R.S. 1971a. A critical appraisal of the environmental movement. Proceedings of the 1970 National Convention, Society of American Foresters, 1970.**

Although Earth Day in 1970 was considered a failure by its organizers, overall response and participation was considerable. Reflections on movement initiation and where it is going are presented.

**13. Boster, R.S. 1971b. A critical appraisal of the environmental movement. Journal of Forestry 69:12–16.**

Although Earth Day in 1970 was considered a failure by its organizers, overall response and participation was considerable. Reflections on the environmental movement, where it came from and where it is going, are presented.

**14. Boster, R.S. 1971c. Ground water and the environmental movement. Ground Water 9:2–4.**

The importance of water pollution, especially ground water pollution, is discussed in the context of the environmental movement of early 1970s. It is stressed that hydrologists are obligated to make society aware of the connection between ground-water contamination and surface-water pollution.

**15. Boster, R.S.; Daniel, T.C. 1972. Measuring public responses to vegetation management. Arizona Watershed Symposium Proceedings 16:38–43.**

A set of criteria that might be used to judge techniques designed to quantify scenic beauty is presented. A new approach is described based upon a systematic conceptual model and supported by recent research results from Arizona timberlands including work on the Beaver Creek watershed.

**16. Boster, R.S.; Martin, W. 1972. The value of primary versus secondary data in interindustry analysis: a study in the economics of economic models. Annals of Regional Science, 6(2):35–44.**

Neither statistical analysis nor projection comparisons showed that either aggregative component was better in a case study of 2 input-output models; 1 from primary data, 1 from secondary data. The model developed from secondary sources was adequate and considerably less expensive.

**17. Boster, R.S.; O'Connell, P.F.; Thompson, J.C. 1974. Recreation uses change Mogollon Rim economy. Arizona Review 23(8–9):1–7.**

An economy based on cattle and wood has changed to one based on second homes, retirement living, and transient recreation. Safeguards are inadequate to prevent environmental degradation associated with rapid population and economic growth. The problems and solutions are equally complex.

**18. Brown, T.C. 1976. Alternatives analysis for multiple use management: A case study. USDA Forest Service, Research Paper RM-176.**

An application of the multiple-use principle using economic analysis to evaluate management alternatives on a mixed conifer watershed is presented. Physical yields of sawtimber, pulpwood, water, and forage, and affects on wildlife habitat and esthetics are estimated for 6 alternatives reflecting a variety of management emphases.

**19. Brown, T.C. 1981. Tradeoff analysis in local land management planning. USDA Forest Service, General Technical Report RM-82.**

A set of concepts, procedures, and displays is presented to promote land management planning at the local level. The emphasis is on tradeoffs (analysis) in the formulation on alternatives, the estimation of the effects of the alternatives, and the comparison of the alternatives.

**20. Brown, T.C. 1984. The concept of value in resource allocation. Land Economics 60:231–246.**

Value concepts relevant to the task of resource allocations are described.

**21. Brown, T.C. 1987. Production and cost of scenic beauty: examples for a ponderosa pine forest. Forest Science 33:394–410.**

Psychophysical models of scenic beauty for an all-aged ponderosa pine area are combined with estimates of management costs and physical output values to indicate more efficient input combinations for production of scenic beauty. The scenic beauty models are used to examine tradeoffs between scenic beauty and net present worth from timber, forage, and water yields.

**22. Brown, T.C.; Boster, R.S. 1974. Effects of chaparral-to-grass conversion on wildfire suppression costs. USDA Forest Service, Research Paper RM-119.**

Properly planned, executed, and maintained chaparral-to-grass conversion should reduce the occurrence of large, expensive wildfires. The dollar values of "fire benefits" were calculated for 141 convertible areas in Arizona's Salt-Verde Basin. The fire benefit, although not as high as water and forage benefits resulting from conversion, is an important addition to a benefit-cost analysis. While transference of dollar values to other areas is tenuous, the methodology is transferable and can be a useful planning tool.

**23. Brown, T.C.; Boster, R.S. 1978. On the economics of timber damage appraisal for public forests. Journal of Forestry 76:777–780.**

Damage appraisal is the basis for fire-suppression decisions. Where timber is managed for production of maximum site rent, appraisal is a matter of applying standard financial criteria in a "with and without" procedure. Where timber is managed for production of maximum mean annual increment, as often occurs on public forests, this procedure may yield seemingly incongruous results. Ignoring "with and without" in public decision making may result in over expenditure for fire suppression.

**24. Brown, T.C.; Carder, D.R. 1977. Sustained yield of what? Journal of Forestry 75:722–723.**

Because effective land management must provide sufficient flexibility for the forest- product mix to respond to changing needs, the authors suggest that the focus of sustained yield management be shifted from individual outputs toward managing for a maximum sustained yield of the total value of forest output.

**25. Brown, T.C.; O'Connell, P.F.; Hibbert, A.R. 1974. Chaparral conversion potential in Arizona. Part II. An Economic Analysis. USDA Forest Service, Research Paper RM-127.**

Some 139 chaparral areas totaling 332,796 acres meet crown cover, slope, and managerial criteria for conversion. Using fire for conversion, 96 areas have a benefit-cost ratio greater than 1; using soil-applied herbicide, 72 areas meet that economic criterion. Other resources should be favorably affected.

**26. Clary, W.P. 1983. Interfacing physical data and economics. In: Proceedings of the Range Economics Symposium and Workshop, August 31–September 2, 1978, Salt Lake City, Utah, USDA Forest Service General Technical Report INT-149. pp. 115–119.**

Four areas of information are presented that are often overlooked when dealing with economic analyses of rangeland activities. The areas are statistical sampling errors in the physical data, differences in site productivity, lack of a uniform product, and lack of consideration for maximizing land output considering several products or uses.

**27. Ekholm, A. 1977. The impact of tourism in the Flagstaff trade area. Northern Arizona Economic Review 3(4):4.**

A complete analysis of the input-output interrelationships in the Flagstaff area is presented. The economic model used accounts for the interrelationships of individuals, businesses, and government units in the trade area for 1973.

**28. Eskandari, A.; Ffolliott, P.F.; Szidarovszky, F. 1994. Multicriterion decision- making for sustainable watershed resources management. Pure Mathematics and Applications 5:379–390.**

Two watersheds in the pinyon-juniper woodlands of north central Arizona that had been subjected to conversion treatments to affect multiple-use values are compared to a third watershed that remained as a control. Multicriterion decision-making techniques were useful in evaluating the 2 treatments in a multiple-use context. The problem confronted is discrete with quantitative and qualitative criteria. The normalized weighing method was used and a sensitivity analysis was performed in funding the most appropriate treatment.

**29. Eskandari, A.; Ffolliott, P.F.; Szidarovszky, F. 1995a. Uncertainty in multicriterion watershed management problems. Technology: Journal of the Franklin Institute 332A:199–307.**

A multicriterion decision making (MCDM) problem, where the payoff values were considered uncertain, is examined. This uncertainty was treated by a special simulation method, where 100,000 random payoff matrices were generated and the best decision alternative selected for each case by the normalized weighing method. This combination of MCDM methodology and stochastic simulation is the basis for a special expert system that was used in this study and can be applied in similar cases of watershed management. This study shows that simulation provides more realistic decisions and, therefore, is recommended to practitioners when the required data inputs are available.

**30. Eskandari, A.; Ffolliott, P.F.; Szidarovszky, F. 1995b. Decision support system in watershed management under uncertainty. In: Mousavi, S. F., and M. Karamooz, M., editors. Regional Conference on Water Resources Management, Isfahan University of Technology, Isfahan, Iran, August 28–30, 1995, pp. 155–164.**

This paper examines the probabilistic model to address watershed management problems. The most frequently used multicriterion decision making (MCDM) technique, the distance-based method, was used to determine the suitability of the MCDM technique in solving watershed management problems. Results indicated that the best alternative selection is significantly influenced by the uncertainties of the payoff values in practical problems.

**31. Eskandari, A.; Ffolliott, P.F.; Szidarovszky, F. 1995c. Decision support system in watershed management. In: Ward, T.J., ed. 1995. Watershed management: Planning for the 21st century. American Society of Civil Engineers, New York, pp. 208–217.**

A decision support system based on multi objective programming techniques is presented. Applying the system to solve a watershed management problem is also described.

**32. Eskandari, A.; Ffolliott, P.F.; Szidarovszky, F. 1995d. Uncertainty and method choice in discrete multi objective programming problems. Applied Mathematics and Computations 69:335–351.**

Discrete multi objective programming problems are examined under uncertain knowledge of the payoff values. Besides mean value analysis, 2 types of distributions are considered, triangular and uniform probability functions. A problem in watershed management illustrates the methodology.

**33. Fogel, M.; Ffolliott, P.F.; Tecle, A. 1988. Multi-purpose management of forest resources. In: Kent, B.M., and L.S. Davis, tech. coords. The 1988 symposium on systems analysis of forest resources. USDA Forest Service, General Technical Report RM-161, pp. 24–29.**

A framework for applying multicriterion decision-making techniques to the management of Southwestern United States ponderosa pine is presented. The procedure consists of stochastic precipitation and temperature models as inputs into simulation models of forest-based products, and decision-making routines that evaluate alternatives considering environmental consequences and commensurate values.

**34. Kelso, M.M. 1962. Economic of upstream management. Society of American Foresters Proceedings 1962:120–123.**

People interested in or responsible for watershed management must make decisions concerning the following questions: what to produce from the watershed, how much of each product to produce, how to produce it, for whom should it be produced, and when should it be produced? This paper considers the answers to these questions.

**35. Kelso, M.M.; Mack, L. 1964. The value of additional surface water to agriculture in the Salt River Project. Arizona Watershed Symposium Proceedings 8:40–47.**

The value of using the additional quantities of runoff produced in the Salt-Verde watershed for agricultural purposes is examined.

**36. King, D.A.; Ffolliott, P.F. 1972. Rate of value increase: A decision guide for timber management. Progressive Agriculture in Arizona 24:13–3, 16.**

Rate of value increase, which is an application of the concept of financial maturity, is presented as a guide in deciding when to harvest individual ponderosa pine trees. When the value of other forest products and services is considered, knowing the value rate provides managers with an estimate of the timber opportunity costs when furnishing these other goods and services.

**37. Lloyd, R.D. 1969. Economics of multiple use. Conference on Multiple-Use of Southern Forests Proceedings. 1969:45–54.**

Multiple use has been a useful philosophy and policy guide, but an operational system for multiple-use planning and management from an economic viewpoint has not been developed. As forest goods and services become scarce and increase in value, management for single products and primary products will have to be replaced with management that involves tradeoffs among competitive products.

**38. Martin, W.E.; Snider, G.B. 1979. Valuation of water and forage from the Salt- Verde Basin of Arizona. University of Arizona, Final Report Prepared by the Department of Agricultural Economics, Tucson, Arizona, Prepared for USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The primary goal of this report was to estimate the current aggregate and marginal values of water and forage in the Salt-Verde Basin as well as the expected changes in these values for a 40-year period.

**39. Martin, W.E.; Snider, G.B. 1980. The value of forage for grazing cattle in the Salt-Verde Basin of Arizona. University of Arizona, Department of Agricultural Economics, Report No. 22, Tucson, Arizona, Prepared for USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Estimates of the current aggregate and marginal values of water and forage in the Salt-Verde Basin are presented along with the expected changes in these values for a 40-year period.

**40. Miller, R.L. 1969. Progress in developing multiple-use forest watershed production models. Annals of Regional Science 3:135–142.**

Research is underway on the Salt and Verde rivers watersheds in Arizona to determine how to redirect management to produce more water, while providing for expected increases in wildland recreation use and the sustained demand for timber and grazing. Particular attention is paid to development of basic models for analysis and decision making in multiple-use watershed management.

**41. Miller, R.L. 1971. Clearing an alligator juniper watershed with saws and chemicals: A cost analysis. USDA Forest Service, Research Note RM-183.**

Manpower, equipment, materials, and vehicle input data were analyzed for jobs involved in the conversion of a juniper watershed to herbaceous cover in north central Arizona. Analysis indicates that costs may be reduced substantially in an operational program through improved organization, changing prescriptions and techniques, and further cost studies.

**42. Miller, R.L.; Johnsen, T.N. 1970. Effects of tree and sawyer factors on costs of felling large alligator junipers. USDA Forest Service, Research Paper RM-56.**

Effects of tree characteristics, working conditions, and sawyer factors on juniper felling times in north central Arizona and suggested alternatives that can be adopted to improve operational efficiency are presented.

**43. Miller, R.L.; Larson, F.R. 1973. A cost analysis of clearing a ponderosa pine watershed. USDA Forest Service, Research Note RM-231.**

After a commercial logging operation, the cost of felling unmerchantable small trees and windrowing slash was $72.09/acre. Costs could probably be reduced 40% or more using different treatment prescriptions and equipment, and by removing pulpwood and firewood where markets are available.

**44. O'Connell, P.F. 1971. Economic modeling in natural resource planning. Arizona Watershed Symposium Proceedings 14:31–38.**

Historically, minimal management was required for nonmarket products from forested land because of limited demand and a plentiful supply. Currently, an increasing population with sophisticated wants and more education, political awareness, leisure time, and disposal income has applied pressure to manage natural resources for market products and nonmarket products.

**45. O'Connell, P.F. 1972a. Economics of chaparral management in the Southwest. In: Watersheds in Transition Symposium, Fort Collins, Colorado, June, 1972, American Water Resources Association Proceedings Series 14:260–266.**

A meaningful quantitative analysis can be made of a proposed chaparral management program. On the Tonto National Forest, for example, several million dollars would have be spent on outdoor recreation facilities in water-oriented and ponderosa pine areas before the chaparral areas could compete.

**46. O'Connell, P.F. 1972b. Valuation of timber, forage, and water from National Forest lands. Annals of Regional Science 6:1–14.**

Because some forest products are not sold in the market place, it is difficult to fit their outputs into economic models. Multi-objective alternatives for identifying relative worth include economic efficiency, regional development, and environmental quality. Economic criteria are logical for timber, forage, and consumptive water.

**47. O'Connell, P.F. 1974. Detailed studies in the Salt-Verde watershed. Arizona Watershed Symposium Proceedings 18:52–57.**

A resume of USDA Forest Service Research Paper RM-127 by Brown, T.C., P.F. O'Connell, and A.R. Hibbert 1974, is presented. The economic benefits of converting chaparral vegetation with fire are discussed.

**48. O'Connell, P.F. 1977. Economic evaluation of non-marked goods and services. In: Hughes, J.M., and R.D. Lloyd. Outdoor recreation, advances in application of economics (proceedings of a national symposium). USDA Forest Service, General Technical Report WO-2, p. 82–90.**

State-of-the-knowledge for developing nonmarket values is summarized and a discussion of how to evaluate goods and services that do not fit in an economic framework is presented.

**49. O'Connell, P.F.; Boster, R.S. 1974. Demands on national forests require coordinated planning. Arizona Reporter 23:1–7.**

Alternative uses and increasing resource scarcity require a change from basing allocation policies on simple physical characteristics of resources to the use of economic criteria. Production decisions must consider economic demand and supply. This Mogollon Rim study in Arizona illustrates use of economic values.

**50. O'Connell, P.F.; Brown, H.E. 1970. The use of production functions in multiple-use evaluation of land treatments on the Beaver Creek pilot watersheds. American Geophysical Union Transactions 51:753, Abstracts.**

Product-product functions for water, timber, and herbage are described. Supplementary, complementary, and competitive stages of the functions are identified and used in subsequent evaluations of alternative watershed management treatments.

**51. O'Connell, P.F.; Brown, H.E. 1972. Use of production functions to evaluate multiple use treatments on forested watersheds. Water Resources Research 8:1188–1198.**

Product-product functions were developed for water, timber, and herbage for 5 strip cutting alternatives. They indicate the supplementary, complementary, and competitive outputs obtained from a given expenditure. Outputs and costs were evaluated over a 90-year period.

**52. Poudel, P.K. 1979. Capitalization of environmental benefits into property values: Literature review. USDA Forest Service, General Technical Report RM-69.**

Social benefits derived from public environment improvement projects are one important justification for increasing such projects. Economic theory that predicts environmental benefits are capitalized as property values increase. This paper reviews several empirical studies that use differential property values to demonstrate this capitalization.

**53. Tecle, A. 1988. Choice of multicriterion decision-making techniques for watershed management. PhD Dissertation, University of Arizona, Tucson, Arizona.**

The problem of selecting a multicriterion decision making (MCDM) technique for watershed resources management is investigated. Of concern is matching a watershed resources management problem with the appropriate MCDM technique.

**54. Tecle, A. 1987. Multiobjective forest watershed management. In: Morel- Seytoux, H.J. and T.G. Sanders editors, Proceedings of the Seventh Annual AGU Front Range Branch Hydrology Days, Colorado State University, Fort Collins, CO, April 21–23, pp. 110–125.**

The impact of alternative forest watershed management practices is examined from a multi objective viewpoint to select the most satisfying management scheme. The process is demonstrated using the Beaver Creek experimental watershed as a case study. The desired objectives of the experimental study and alternative treatment schemes performed are arranged into an evaluation matrix of alternatives versus criteria array. Analysis of the matrix using multicriterion decision making techniques results in a complete preference ordering of the alternatives.

**55. Tecle, A.; Covington, W.W.; Wood, D.B.; Fox, B.E. 1989. Conflict resolution in Multi resource forest management via multiobjective analysis. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185. pp. 247–258.**

Methodology are developed and presented for conflict resolution in forest resources management. Sources and possible types of conflicts are identified and some conflict analysis methods are revised. A ponderosa pine forest resources management problem with conflicting objectives is solved. Data from the Beaver Creek Watershed is used in the analyses.

**56. Tecle, A.; Duckstein, L.; Covington, W.W.; Wood, D.B. 1989. Uncertainty and risk in forest management. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185. pp. 208–212.**

A framework is developed for risk and uncertainty analysis in forest management. The elements of this analysis are driven by 5 main issues: 1) forest regeneration, 2) threat to an endangered species, 3) deterioration of wildlife habitat, 4) aesthetics degradation, and 5) water yield.

**57. Tecle, A.; Duckstein, L.; Korhonen, P. 1994. Interactive, multiobjective programming for forest resource**

management. Applied Mathematics and Computation 63:75–93.

This paper demonstrates how a balanced forest resource management program may be attained by a "free search" type interactive multicriterion decision making technique. Information from the Beaver Creek experimental watersheds in north central Arizona is used to demonstrate the technique.

**58. Tecle, A.; Fogel, M.M.; Duckstein, L. 1987. Multicriterion forest watershed resources management. In: Forest hydrology and watershed management: Proceedings of the Vancouver symposium. IAHS-AISH Publication 167:617–625.**

The Beaver Creek experimental watershed is used as a case study consisting of 6 alternative schemes evaluated with respect to 15 noncommensurable, discrete criteria, using 2 types of MCDM techniques the: 1) outranking types of ELECTRE I and II and 2) distance-based type of compromise programming. The result is a complete or partial ranking of nondominant alternatives.

**59. Tecle, A.; Fogel, M.M.; Duckstein, L. 1988. Choice of multicriterion decision making model for forest watershed resources management. In: Kent, B.M., and L.S. Davis, tech. coords. The 1988 symposium on systems analysis in forest resources. USDA Forest Service, General Technical Report RM-161, pp. 59–67.**

An algorithm for selecting a multicriterion decision making (MCDM) technique for forest watershed resources management is modeled as a multicriterion problem. The procedure involves evaluation of feasible alternative MCDM techniques with respect to different sets of choice criteria. A particular technique is used to analyze the problem leading to a preference ranking of the alternative MCDM techniques.

**60. Tecle, A.; Fogel, M.M.; Duckstein, L. 1988. Multicriterion analysis of forest watershed management alternatives. Water Resources Bulletin 24:1169–1178.**

The impacts of alternative forest watershed management practices are examined from a multicriterion viewpoint to select the most satisfactory management scheme. The selection process is carried out using 2 multicriterion decision making techniques and is demonstrated using the Beaver Creek experimental watershed in Arizona.

**61. Tecle, A.; Szidarovszky, F.; Duckstein, L. 1995. Conflict analysis in multi- resource forest management with multiple decision-makers. Nature & Resources 31:8–17.**

Quantitative methods, based on game theory, are used to model multi-resource management problems illustrated by a case study on the Beaver Creek experimental watershed in north central Arizona. Six forest resources management objectives and their interactions are examined. The outcome is a compromise solution that is expected to be satisfactory to all groups involved.

**62. Turner, J.M. 1974. Allocation of forest management practices on public lands. Annals of Regional Science 8:72–88.**

This paper describes a process for integrating product yields, costs, and values into a planning framework that broadly defines management practices on national forest land.

**63. Turner, J.M.; Larson, F.R. 1974. Cost analysis of experimental treatments on ponderosa pine watersheds. USDA Forest Service, Research Paper RM-116.**

A regression model predicts thinning and piling costs as a function of the degree of timber basal area removed in Southwestern pine stands. Thinning costs are related to basal area removed noncommercially, while piling costs are related to total basal area removed.

**64. Wong, P.; Barriga, J.; Carder, D.R. 1976. Methods for estimating traffic volumes and compositions on national forests roads. In: Low-Volume Roads. National Research Council, Transportation Research Board Special Report 160, National Academy of Science, Washington, D.C., pp. 257–266.**

Concepts of traffic-volume sampling and analysis are discussed in terms of probability theory and statistical inference. Modeling techniques were developed to estimate travel generated by recreation, logging, and administration under alternative management strategies.

**65. Worley, D.P. 1961. Objectives and methods of economics evaluation on the Beaver Creek watershed project. Western Agricultural Economics Research Council Conference Proceedings, Report 9:123–129.**

This report discusses important watershed studies on the Coconino National Forest in Arizona, with emphasis on multiple use.

**66. Worley, D.P. 1962. Some problems in range economics research. American Society of Range Management, Arizona Section, Proceedings 1962:37–38.**

How economic research differs from research in the physical fields in method and content is shown. Illustrations are presented that show problems that economists might attempt to solve.

**67. Worley, D.P. 1965. The Beaver Creek pilot watershed for evaluating multiple use effects of watershed treatments. USDA Forest Service, Research Paper RM-13.**

A discussion is presented of the 275,000-acre watershed in north central Arizona where costs and benefits of intensive multiple-use land management are being evaluated as a part of the Arizona Watershed Program.

**68. Worley, D.P. 1966. Economic evaluation of watershed management alternatives of the Beaver Creek Watershed—Arizona. New Mexico Water Conference Proceedings 11:58–65.**

An economic evaluation to estimate the advantages and disadvantages of alternative management practices to increase water yield is discussed. The evaluation must analyze the effects of the alternatives on other resources and the direct and indirect benefit and cost of increased water.

**69. Worley, D.P. 1966. A forest inventory approach to multiple use analysis. Proceedings of the Society of American Foresters 1966:138–142.**

An inventory designed for estimating multiple-use product responses to various management alternatives is presented. This information can be useful to small landowners when deciding the best management strategies to

use on their timbered tracts and can also be used for multiple-use coordination on large management areas.
**70. Worley, D.P.; Miller, R.L. 1964. A procedure for upstream watershed economic evaluation. Arizona Watershed Symposium Proceedings 8:36–39.**

This paper describes the Arizona watershed development program. Because water is important for continued economic development, the watershed management program is designed to: 1) research ways to increase water quantity, 2) evaluate identified approaches on pilot test areas, 3) extend research and test results to estimate the outcome on the river basin scale, 4) develop economic background about the basin, and 5) estimate the benefits and costs of instituting the program on the river basin.

**71. Worley, D.P.; Mundell, G.L.; Williamson, R.L. 1965. Gross job time studies—an efficient method for analyzing forestry costs. USDA Forest Service, Research Note RM-54.**

A special cost study method is described in this report. The method is a flexible, field-efficient, formal system of data collection capable of answering a number of cost questions.

## Erosion and Sedimentation

**72. Baker, M. B., Jr.; DeBano, L.F.; Ffolliott, P.F. 1995. Soil loss in piñon-juniper ecosystems and its influence on site productivity and desired future conditions. In: Shaw, D. W., E. F. Aldon, and C. LoSapio, tech. coords. 1995. Desired future conditions for pinyon-juniper ecosystems. USDA Forest Service, General Technical Report RM-258, pp. 9–15.**

A conceptual framework for describing erosional processes in the pinyon-juniper type is presented with a discussion of the impacts of soil losses on site productivity. Erosion and site productivity information is related to expected changes in the desired future condition of pinyon-juniper woodlands.

**73. Boster, R.S.; Davis, L.R. 1972. Soil-loss considerations in chaparral-to-grass conversions. In: Csallany, S.C., T.G. McLaughlin, and W.D. Striffler, eds., Watersheds in Transition Symposium, Fort Collins, Colorado, June 1972, American Water Resources Association Proceedings Series 14, pp. 243–250.**

Chaparral conversions can be designed with minimal initial sediment loss; vegetative conversions can save soil over time. Properly planned conversions would little, if any, off-site sediment impacts.

**74. Dong, C. 1996. Effects of vegetative manipulations on sediment concentrations in northern-central Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

The effects of manipulations are analyzed within a framework of sediment rating curves. Partitioning the sediment-streamflow data into runoff generation mechanisms and hydrograph stages helped describe the effects in many instances.

**75. Gabbert, W.A.; Ffolliott, P.F. 1985. Prediction of nutrient and heavy metal transport capacities of suspended sediment. In: Proceedings of the Symposium on Watershed Management in the Eighties. American Society of Civil Engineers, Denver, Colorado, April 30–May 1, 1985, pp. 215–219.**

A computerized prediction technique to estimate the impacts of land-management practices on physical and chemical characteristics of transported sediment is described. A hypothetical example is also presented to illustrate that predictions of nutrient and heavy metal transport capacities can be obtained with inputs of on-site data or default values.

**76. Gosz, J.R.; White, C.S.; Ffolliott, P.F. 1979. Nutrient and heavy metal transport capabilities of sediment in the southwestern United States. Final Report for Eisenhower Consortium Grant #255.**

Methodology for characterizing the absorbing capacity of different types of sediments and their potential for transporting nutrients are discussed along with differences in the chemistry and transport capacity of sediments with respect to geologic source and vegetation type.

**77. Gosz, J.R.; White, C.S.; Ffolliott, P.F. 1980. Nutrient and heavy metal transport capabilities of sediment in the southwestern United States. Water Resources Bulletin 16:927–933.**

Results of preliminary tests to compare sediment samples from a ponderosa pine community on basalt, sandstone, limestone, and granite bedrock parent material are presented. A comparison of a pine and mixed conifer community on basalt parent material is also included.

**78. Hansen, E. A. 1966. Suspended sediment concentrations as related to watershed variables in central Arizona. American Society of Civil Engineers, Hydraulics Division, Madison, Wisconsin, August 1966.**

Some factors related to suspended sediment concentration in a semi-arid region are presented. Data used were collected over a 7–year period on the Beaver Creek Watershed in north central Arizona.

**79. Heede, B.H. 1984. Overland flow and sediment delivery: an expe riment with small subdrainage in southwestern ponderosa pine forests (Colorado, USA). Journal of Hydrology 72:261–273.**

Overland flow and sediment delivery were insignificant on 14 small subdrainages in the pine type. Sediment sources were roads and erosion pavements, but sediment from undisturbed forest floor areas was practically nonexistent. Most erosion pavements were believed to be the result of a selected timber harvest 42 years ago, and hypotheses on their development are proposed.

**80. Heede, B.H. 1988. The influence of vegetation and its spatial distribution on sediment delivery from selected Arizona forests and woodlands. In: Erosion control: stay in tune, proceedings of the 19th International Erosion Control Association conference, New Orleans, Louisiana, February 25–26, 1988, pp. 383–392.**

Overland flow and sediment delivery processes in ponderosa pine, mixed conifer, pinyon-juniper, and chaparral watersheds show that spatial distribution of vegetation is more important than vegetation type for erosion control. Sediment delivery was practically nonexistent where buffer strips grew below nonwooded areas.

**81. Lopes, V.L.; Ffolliott, P.F. 1992. Erosion-sedimentation processes on upland watersheds in dryland environment: An initial conceptual development. In: Proceedings of the Southwestern and Rocky Mountain Division, America Association for the Advancement of Science, Sixty-Eighth Annual Meeting, Tucson, Arizona, May 17–21, 1991, p. 30. (Abstract)**

The results from an analysis of streamflow sediment yield from snowmelt runoff events, and the initial efforts in developing a conceptual modeling framework are presented. Data sets representative of upland ponderosa pine watersheds in northern Arizona were used in this paper.

**82. Lopes, V.L.; Ffolliott, P.F. 1993. Sediment rating curves for a clearcut ponderosa pine watershed in northern Arizona. Water Resources Bulletin 29:369–382.**

Analysis of suspended sediment concentration and streamflow discharge relationships from a ponderosa pine watershed recovering from a clearcut treatment is presented. Variability associated with seasonal effects is reduced by considering streamflow generating mechanisms.

**83. Lopes, V.L.; Ffolliott, P.F. 1995. Effects of forest harvesting practices on streamflow-sediment relationships for southwestern ponderosa pine watersheds. In: Ward, T. J., ed. 1995. Watershed management: Planning for the 21st century. American Society of Civil Engineers, New York, pp. 64–72.**

Effects of forest harvesting practices on suspended sediment-streamflow relationships are described. A clearcut watershed produced the highest suspended sediment concentrations. Higher suspended sediment concentrations were observed during the rising stage than for similar flows on the falling stage of the hydrographs.

**84. Lopes, V.L.; Ffolliott, P.F.; Gottfried, G.J.; Baker, M.B., Jr. 1996. Sediment rating curves for pinyon-juniper watersheds in north-central Arizona. Hydrology and Water Resources in Arizona and the Southwest 26:29–33.**

Analysis of suspended sediment concentration-streamflow discharge relationships for 2 pinyon-juniper watersheds that had vegetative conversion treatments, and a control watershed representing untreated conditions is presented. Comparisons among the watersheds provide a basis for determining the effects of the conversion treatments on sedimentation processes.

**85. Ward, T.J. 1983. Interpretation and analysis of Beaver Creek sediment research data. Final Report Prepared by New Mexico State University, Las Cruces, New Mexico, Submitted to the Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona.**

Sediment concentration and yield data for 9 ponderosa pine watersheds in north central Arizona are presented. Most runoff and sediment yields occur during winter snowmelt; summer runoff and sediment yields are nonexistent except for infrequent large, high intensity thunderstorms.

**86. Ward, T.J.; Baker, M.B., Jr. 1984. Sediment from managed pine watershed in northern central Arizona. Reprinted from Proc. of the Specialty Conference. Sponsored by Irrigation and Drainage Div., ASCE [Flagstaff, AZ., July 24–26, 1984]. pp. 552–558.**

Data from the last 20 years indicate an initial, marked increase in sediment yield following treatment. The degree of increase is related to the degree of management activity and the intensity of runoff.

**87. Wigdor, Y. 1994. Applicability of selected sediment transport equations to pinyon-juniper woodlands. MS Thesis, University of Arizona, Tucson, Arizona.**

None of 8 sediment transport formulas tested accurately predicted the sediment discharges measured on 3 pinyon-juniper watersheds in north central Arizona. However, a logarithmic correction factor was developed to adjust the predictions obtained from the formulas to represent actual measurements.

**88. Wigdor, Y.; Lopes, V.L.; Ffolliott, P.F. 1996. Comparison of sediment discharge predictions for small watersheds in the southwestern United States. International Journal of Sediment Research 11:22–33.**

Streamflow-sediment discharges from 3 pinyon-juniper watersheds were used to test the applicability of 2 total-load formulas; those developed by Yang and Engelund-Hansen. The comparison shows that the formulas over predicted sediment discharges in ephemeral streams under the sediment-supply-limited conditions studied. A logarithmic relationship adjusted the sediment discharges computed by the formulas to provide satisfactory predictions of sediment-transport rates.

## Fire

**89. Beaulien, J.T. 1975. Effects of fire on understory plant populations in a northern Arizona ponderosa pine forest. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

Determination of the nature and extent of fire-caused changes on herbage production and species composition is presented.

**90. Campbell, R.E.; Baker, M.B., Jr.; Ffolliott, P.F.; Larson, F.R.; Avery, C.C. 1977. Wildfire effects on a ponderosa pine ecosystem. USDA Forest Service Research Paper RM-191.**

In 1972, 90% of the small trees and 50% of the sawtimber were killed in areas of intense fire. Initially high water yields declined each year toward prefire levels. Successional changes provided up to 1,650 lbs/acre of herbage production compared to about 515 lbs/acre in unburned forest.

**91. Davis, J.R. 1965. A survey of an intentional burn in Arizona ponderosa pine. USDA Forest Service, Research Note RM-41.**

Results of a 100-acre burn are presented including information on burning conditions, fire intensity, and affects on understory trees.

**92. Davis, J.R.; Ffolliott, P.F.; Clary, W.P. 1968. A fire prescription for consuming ponderosa pine duff. USDA Forest Service, Research Note RM-115.**

A prescribed fire that burned a specific quantity of pine litter in north central Arizona is described. This objective is accomplished along with thinning of the overstory from below, increased seedling germination, and temporary fire hazard reduction.

**93. DeBano, F.L.; Baker, M.B., Jr.; Ffolliott, P.F. 1995. Effects of prescribed fire on watershed resources: A conceptual model. Hydrology and Water Resources in Arizona and the Southwest. 22-25:39–44.**

A simple conceptual model is developed relating fire severity to watershed and soil response for vegetation and climatic conditions in the Southwestern United States.

**94. DeBano, L.F.; Baker, M.B., Jr.; Ffolliott, P.F.; Neary, D.G. 1996. Fire severity and watershed resource response in the Southwest. Hydrology and Water Resources in Arizona and the Southwest 26:39–43.**

Further development of a conceptual model of the effects of fire severity on postfire hydrologic responses is described. Examples of applications in ponderosa pine forests, chaparral, and other Southwestern vegetative types is also presented.

**95. Ffolliott, P.F. 1990. Opportunities for fire management in the future. In: Krammis, J. S., tech. coord. Effects of fire in management of southwestern natural resources. USDA Forest Service, General Technical Report RM-191, pp. 152–167.**

Coniferous forests, pinyon-juniper woodlands and chaparral, and desert shrub and grassland communities are considered in this review. Opportunities for fire management include fuel load reductions, slash disposal, seedbed preparation, stand thinning of, increasing herbaceous production, improving wildlife habitats, changing hydrologic characteristics, and improving esthetics. Concerns and constraints to the use of fire must also be considered.

**96. Ffolliott, P.F.; Guertin, D.P. 1990. Prescribed fire in Arizona ponderosa pine forests: A 24-year case study. In: Krammis, J. S., tech. coord. Effects of fire in management of southwestern natural resource. USDA Forest Service, General Technical Report RM-191, pp. 250–254.**

Effects of fire on litter accumulations, needle deposition, tree mortality, forest density, seedling survival, and herbage production are described. Change in the fire hazard also evaluated.

**97. Ffolliott, P.F.; Clary, W.P.; Larson, F.R. 1976. Fire scene: 11 years after. Progressive Agriculture Arizona 28:12–13.**

A small prescribed fire on the Coconino National Forest in Arizona reduced fire hazard and timber density. Fire-killed branches and trees have since contributed greatly to new fuel levels. Basal area levels are still too high.

**98. Ffolliott, P.F.; Clary, W.P.; Larson, F.R. 1977. Effects of a prescribed fire in an Arizona ponderosa pine forest. USDA Forest Service, Research Note RM-336, 4 p.**

A prescribed fire consumed nearly three-fourths of the total forest floor. Eleven years later, forest floor depth was two-thirds that of the prefire level. More pine seedlings started on the burned areas than under adjacent unburned stands and herbage production increased, but not to levels adequate for grazing.

**99. Kruse, W.H. 1972. Effects of wildfire on elk and deer use of a ponderosa pine forest. USDA Forest Service, Research Note RM-226.**

Elk and deer response to conditions following a wildfire in north central Arizona is described.

**100. Lowe, P.O. 1975. Potential wildlife benefits of fire in ponderosa pine forests. MS Thesis, University of Arizona, Tucson, Arizona.**

Benefits and losses from fire are described in terms of an index that could be used when analyzing postfire values. Flows of benefits or losses, called time-trend response functions, are converted to annuities for this purpose.

**101. Lowe, P.O.; Ffolliott, P.F.; Dieterich, J.H.; Patton, D.R. 1978. Determining potential wildlife benefits from wildfire in Arizona ponderosa pine forests. USDA Forest Service, General Technical Report RM-52.**

An index of benefits from wildfire that converts the flows of benefits or losses after fire to annuities is described. By assuming values for wildlife use, these changes can be interpreted in terms of dollars to describe the total impact of wildfire on the wildlife resource.

**102. Pearson, H.A., Jr.; Davis, R.; Schubert, G.H. 1972. Effects of wildfire on timber and forage production in Arizona. Journal of Range Management 25:250–253.**

A severe May wildfire decimated an thick ponderosa pine stand; an adjacent thinned stand was relatively undamaged. Radial growth increased on burned trees with less than 60% crown kill. Burning initially stimulated growth and nutrient value of herbaceous vegetation in both stands. Seeded areas produced most herbage after 2 years.

**103. Sims, B.D. 1979. Effect of fire on water quality in an Arizona ponderosa pine forest. MS Thesis, University of Arizona, Tucson, Arizona.**

Effects of a controlled burn on fluoride, calcium, magnesium, pH, and other water quality constituents are described and compared with similar information obtained following a wildfire. Equations are presented to predict postfire changes in some of these constituents in relation to fire intensity, time since the burn, and precipitation in postfire storm events.

**104. Sims, B.D.; Lehman, G.S.; Ffolliott, P.F. 1981. Some effects of controlled burning on surface water quality. Hydrology and Water Resources in Arizona and the Southwest 11:87–90.**

Preburn and postburn water samples were collected from surface runoff plots near Tucson, Arizona, to provide insights to the effects of controlled burning. While some changes in dissolved chemical concentrations occurred immediately after the fire, these changes were not detrimental in terms of water quality standards for drinking and irrigation water.

**105. Wells, C.G.; Campbell, R.E.; DeBano, L.F.; Lewis, C.E.; Fredridsen, R.L.; Franklin, E.C.; Froelich, R.C.; Dunn, P.H. 1979. Effects of fire on soil: A state-of-knowl-**

edge review. USDA Forest Service, General Technical Report WO-7.

Summary of information about the effects of fire on soil properties are presented along with more specific data for certain forests, brush, and range types.

## Geographic Information Systems

**106. Rasmussen, W.O.; Ffolliott, P.F. 1978a. Error processing systems for integrated resource data. In: Lund, H.G., V.J. LaBau, P.F. Ffolliott, and D.W. Robinson, tech. coords. Integrated inventories of renewable natural resources: Proceedings of the workshop. USDA Forest Service, General Technical Report RM-55, pp. 328–331.**

A land-use planning tool is presented that has the ability to check data points in associated data bases for inconsistencies. Products produced from data that has been checked for errors have greater verity.

**107. Rasmussen, W.O.; Ffolliott, P.F. 1978b. Should an organization use existing data or collect new? In: Proceedings of a Workshop on Computer Systems in the Field. Sponsored jointly by Society of American Foresters and Iowa State University Ames, pp. 128–138.**

An approach is presented that allows land-management organizations to determine whether to use existing or new data for a given project.

**108. Rasmussen, W.O.; Ffolliott, P.F. 1981a. Ecosystem response simulation as an aid in computer assisted utility corridor siting. In: Symposium on environmental concerns in rights-of-way management, U.S. Fish and Wildlife Service and the Electric Power Research Institute, Ann Arbor, Michigan, October 16–18, 1979, pp. 2-1–2-7.**

Siting of a utility corridor requires consideration of economic, sociopolitical, engineering, and environmental factors. Ecosystem component simulators have been developed to assist planners in addressing environmental concerns. Their application is discussed, in addition to a computer system used for corridor selection from compositing of geographic data.

**109. Rasmussen, W.O.; Ffolliott, P.F. 1981b. Surface area corrections applied to a resource map. Water Resources Bulletin 17:1079–1082.**

A technique is presented, using a topographic map, for computing the difference in the horizontal planar area of a watershed and the actual surface area, and yielding a prediction of the actual surface area. Spatial variations in the magnitude of the difference in the 2 areas are displayed on computer generated maps.

**110. Rasmussen, W.O.; Ffolliott, P.F.; Halfter, G. 1981. Storage, manipulation, and display of geographic multiresource data for La Michilia Biosphere Reserve in Mexico. In: Lund, H.G., M. Caballero, R.H. Hamre, R.S. Driscoll, and W. Bonner, eds. Arid land resource inventories: Developing cost-efficient methods. USDA Forest Service, General Technical Report WO-28, pp. 528–533.**

A multi-topic geographic data management system in which the location of site-specific data can be stored, manipulated, and displayed to predict management outcomes is described. Descriptions of vegetation, topography, climate, geology, soils, and land capability are included.

**111. Rasmussen, W. O.; Thames, J.L.; Ffolliott, P.F. 1980. Predicting the spatial variation in erosion. In: Symposium on making watershed management work. American Society of Civil Engineers, Boise, Idaho, July 21–23, 1980, pp. 781–789.**

A technique for estimating the spatial and total erosion is presented. This technique uses the Universal Soil Loss Equation (USLE) to predict soil erosion before and after a management change. The computer model uses commonly available data as inputs, with the output displayed in printer maps, perspective plots, and other graphic formats.

**112. Rasmussen, W. O.; Weisz, R.N.; Ffolliott, P.F.; Carder, D.R. 1980. Planning for forest roads—a computer-assisted procedure for selection of alternative corridors. Journal of Environmental Management 11:93–104.**

Application of a computer-oriented tool to ensure appropriate consideration of environmental constraints in the transportation planning process is described. Scenic beauty estimators are used to illustrate how environmental parameters can be considered when locating road corridors.

## Geology

**113. Benfer, J.A.; Beus, S.S. 1968. The relationship of cinders to runoff in the Beaver Creek watersheds. Final Report Prepared by Northern Arizona University, Flagstaff, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A study to determine the relationship between cinder distribution and runoff on small watersheds in north central Arizona is described based on a limited amount of data. Tentative results indicate that greater runoff occurs in watersheds having greater cinder cover; cinder cover appears to enhance rather than reduce runoff potential.

**114. Beus, S.S. 1968. Gravity data from the Beaver Creek Watersheds, Coconino County, Arizona. Final Report Prepared by Northern Arizona University, Flagstaff, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Gravity measurements indicate a general trend of decreasing values or decreasing density of rocks from south to north on the watershed. Abnormally low values are associated with cinder cones, and suggest that they are predominantly composed of pryroclastic fragments and have minor or no basaltic plugs beneath.

**115. Beus, S.S.; Rush, R.W.; Smouse, D. 1966. Geologic investigation of experimental drainage basins 7–14, Beaver Creek Watershed, Coconino County, Arizona. Final Report Prepared by Northern Arizona University, Flagstaff, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Descriptions and interpretation of geologic features that might affect runoff and sedimentation within the watershed region are presented.

**116. Emmons, P.J. 1977. Relationship between seismic velocity, degree of weathering, and seepage potential: Watershed 17, Beaver Creek watershed, Coconino County, Arizona. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

Use of seismic refraction to determine water loss areas to deep seepage on a ponderosa pine watershed was evaluated in north central Arizona.

**117. Ffolliott, P.F.; Fishers, D.L.; Thorud, D.B. 1972. A physiographic survey of the ponderosa pine type on the Salt-Verde River Basin. Agricultural Experiment Station, Technical Bulletin 200, University of Arizona, Tucson.**

Information presented includes slope and aspect relationships, elevation characteristics, rock types (igneous, sedimentary, or metamorphic), and geologic formations. Additionally, information summarizing ownership patterns is provided.

**118. McCabe, K.W. 1971. A geo-botanical study of Stoneman Lake, Wet Beaver Creek experimental drainage basin, Coconino County, Arizona. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

An investigation of Stoneman Lake is presented that includes lake sediments, volcanic features, and vegetation. Stoneman Lake basin is estimated to have collapsed about 300,000 years ago. Using carbon 14 dating to age the sediments, an age of 3940 years B.P., and a sedimentation rate of about 1000 years/ft is determined. Oxidizing and dry conditions have existed throughout the period of known history. The advent of man is marked by a sharp increase in sedimentation rate and by the introduction of nonnative plants and animals.

**119. McCain, R.G. 1976. Relationship between water loss from stream channels and gravity and seismic measurements: Beaver Creek watershed 7, Coconino County, Arizona. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

Suspected water loss zones through highly porous and fractured bedrock zones in north central Arizona were examined using gravity and seismic velocity measurements to see if these techniques can be used to verify and map the aerial distribution of water loss areas.

**120. Rush, R.W. 1965. Report of geologic investigations of six experimental drainage basins, Beaver Creek Watershed, Yavapai County, Arizona. Final Report Prepared by Northern Arizona University, Flagstaff, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Descriptions and interpretation of geologic features that might affect runoff and sedimentation within the watershed region in north central Arizona are presented.

**121. Rush, R.W.; Smouse, D. 1968. Geologic investigation of experimental drainage basins 15–18 and Bar M Canyon, Beaver Creek Watershed, Coconino County, Arizona. Final Report Prepared by Northern Arizona University, Flagstaff, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Descriptions and interpretation of geologic features that might affect runoff and sedimentation within the watershed region in north central Arizona are presented.

**122. Scholtz, J.F. 1968. Geology of the Woods Canyon drainage basin, Coconino County, Arizona. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

A description and interpretation of the geology of Woods Canyon watershed in north central Arizona is presented to assist in future analysis of runoff and sedimentation from the basin.

**123. Scholtz, J.F. 1969a. The Beaver Creek volcanics: a new formation, Coconino- Yavapai Counties, Arizona. Geological Society of America Bulletin 80:2637–2643.**

Cenozoic volcanic rocks form the surface of the Wet Beaver watershed. These rocks had been considered part of the previously reported Hickey Formation. However, these volcanic rocks are defined and characterized as a separate and distinct formation in this paper.

**124. Scholtz, J.F. 1969b. Evidence for revision of the name Hickey Formation east of the Verde Valley, Coconino County, Arizona. Journal of Arizona Academy of Science 5:182–183.**

The oldest lavas of the Beaver Creek Watershed in north central Arizona lie above and inter tongue with the Verde Formation. Although these lavas are younger than the Hickey Formation, they cannot be considered to be a part of the formation.

**125. Scholtz, J.F. 1969c. Investigation of low-stage transmission losses in stream channels on watersheds 7, 9, 11, and 12; Beaver Creek experimental drainage basin, Coconino County, Arizona. Final Report Prepared by Northern Arizona University, Flagstaff, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Measurements and description of transmission losses occurring within the watershed areas in north central Arizona are presented.

**126. Thompson, J.R., Jr. 1968. Geology of Wet Beaver Creek Canyon, Yavapai County, Arizona. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

The stratigraphic and structural trends in Wet Beaver Creek Canyon are presented. The study indicates that the Mogollon Rim is an erosional escarpment rather than a single fault scarp. Springs are controlled by the joint systems and planes of weakness in the sedimentary rock units rather than by the major fault systems.

## Hydrology

**127. Aldon, E.F. 1958. A wet year on Beaver Creek. Arizona Wildlife-Sportsman 29:22.23.**

This report describes watershed management experiments in 3 vegetation types. Other components of the hydrologic cycle are also being studied.

**128. Anderson, R.J. 1980. Relationship between rainfall and storm runoff for selected Arizona watersheds. MS Thesis, Utah State University, Logan, Utah.**

This study examines the use of runoff curve numbers and runoff fractions as models for predicting rainstorm runoff volume from pinyon-juniper and ponderosa pine watersheds in north central Arizona.

**129. Avery, C.C.; Baker, M.B., Jr. 1980. Evaluating hydrologic responses to forest activities. In: Symposium on watershed Management, Proceedings of American Society of Civil Engineers, Watershed Management Symposium, Irrigation and Drainage Division, pp. 485–493.**

Hydrologic models can assist in determining wise land use. Three basic types of models are defined and within each type a range of varying model complexity. Subjective guidelines are provided along with an annotated list of some currently available hydrologic models.

**130. Baker, M.B., Jr. 1981. Hydrologic regimes of three vegetation types across the Mogollon Rim. Hydrology and Water Resources in Arizona and the Southwest 11:5–12.**

Preliminary analyses of the hydrologic regimes of the pinyon-juniper woodland and ponderosa pine forest type in north central Arizona are presented. Analyses are based on 22 years of record.

**131. Baker, M.B., Jr. 1982a. Hydrologic regimes of forested areas in the Beaver Creek watershed. USDA Forest Service, General Technical Report RM-90.**

Hydrologic regimes of the pinyon-juniper woodland and ponderosa pine forest type in north central Arizona are characterized based on 22 years of record. Winter precipitation is most important to streamflow production. Mean annual peak discharge is higher and more frequent in the summer in the woodland type than in the pine type.

**132. Baker, M.B., Jr. 1982b. Influence of clearing ponderosa pine on timing of snowmelt runoff. Western Snow Conference 50:20–26.**

Snowmelt regimes on 2 pine watersheds in north central Arizona are analyzed and the influence of clearing the forest overstory on the timing of concentrated winter-spring runoff is described.

**133. Baker, M.B., Jr. 1987. Diversity in streamflow response from upland basins in Arizona. In: Troendle, C.A., M.R. Kaufmann, R.H. Hamre, and R.P. Winokur, Technical Coordinators. Management of subalpine forests: building on 50 years of research: proceedings of a technical conference; July 6–9, 1987, Silver Creek, CO., USDA Forest Service, General Technical Report RM-149, pp. 211–215.**

Although water yield from a basin is a function of a number of factors, soil depth is foremost in explaining hydrograph differences from the study area. The most attenuated hydrograph was in the chaparral vegetation type, which has the greatest soil depth, while the most responsive or peaked hydrographs were in the pinyon-juniper and ponderosa pine types, which have soil depths of 3 ft or less.

**134. Baker, M.B., Jr.; Brown, H.E.; Champagne, N.E., Jr. 1971. Hydrologic performance of the Beaver Creek watersheds during a 100-year storm. American Geophysical Union Transactions 52:828. (Abstract)**

Results of a major storm that struck the watershed are presented. The recurrence interval for the flood runoff ranged between 100 and 200 years for the pine watersheds. Estimates of treatment effects are determined graphically, based on the relationship between peak discharge and 60-minute precipitation intensity.

**135. Beschta, R.L. 1974. Streamflow hydrology and simulation of the Salt River Basin in central Arizona. PhD Dissertation, University of Arizona, Tucson, Arizona.**

A continuous simulation streamflow model is evaluated and used to study winter streamflow from the Salt River Basin. This watershed ranges in elevation from 2,200 to 11,500 ft and is associated with a diversity of watershed, vegetation, climatic, and hydrologic characteristics.

**136. Brown, H.E. 1965. Characteristics of recession flows from small watersheds in a semiarid region of Arizona. Water Resources Research 1:517–522.**

Recession flows from small watersheds in north central Arizona are described and differentiated on the basis of watershed precipitation and vegetative cover.

**137. Decker, J.P.; Skau, C.M. 1964. Simultaneous studies of transpiration rate and sap velocity in trees. Plant Physiology 39:213–215.**

The relationship between sap-flow velocity and transpiration rates in conifer species in north central Arizona are presented. Sap velocity and actual transpiration rate are closely correlated for intact trees.

**138. Ffolliott, P. F. 1991. Winter course of transpiration in Arizona ponderosa pine trees. Hydrology and Water Resources in Arizona and the Southwest 21:77–79.**

A heat-pulse velocity meter that measures sap movement was used to determine whether transpiration occurs. Sap movement was detected in all of the 10 sample trees in the weekly measurements, with the exception of when 3 of the trees were frozen at the sampling points.

**139. Ffolliott, P.F.; Brooks, K.N. 1990. Forest hydrology and watershed management in the world. In: Ffolliott, P.F., and D.P. Guertin, eds. Proceedings of a workshop: Forest hydrological resources in China—An analytical assessment. U.S. Department of State, Publication 9829, pp. 22–54.**

A review of forest hydrology and watershed management research in 3 geographic-climatic regions of the world is considered. Specifically, an overview of research programs in temperate regions, humid tropical forests, and drylands is presented. Research programs are grouped into catchment experiments, process studies, and computer simulation modeling.

**140. Ffolliott, P.F.; Brooks, K.N. 1993. Process studies in forest hydrology: A worldwide review. In: Pre-Conference Proceedings of the International Conference on Hydrology and Water Resources, New Delhi, India, December 20–22, 1993, pp. 52–53. (Abstract)**

A review of process studies conducted in the temperate regions, humid and subtropical forests, and drylands of the world is presented.

**141. Ffolliott, P.F.; Brooks, K.N. 1996. Process studies in forest hydrology: A worldwide review. In: Singh, V.P., and B. Kumar, editors. Surface-Water Hydrology. Kluwer Academic Publishers, The Netherlands, pp. 1–18.**

A review of process studies conducted in the temperate regions, humid and sub-tropical forests, and drylands of the world is presented. Water balance components considered are interception, evapotranspiration, and infiltration. The role of process studies in improving operational watershed management is stressed.

**142. Ffolliott, P.F.; Lopes, V.L. 1993. Process studies in watershed hydrology: A worldwide review In: Proceedings of the First International Seminar of Watershed Management. University of Sonora, Hermosillo, Mexico, November 17–18, 1992, pp. 87–104.**

Results of studies from the Beaver Creek watersheds are presented. Interception, evapotranspiration, and infiltration are considered.

**143. Ffolliott, P.F.; Fogel, M.M.; Thames, J.L. 1982. Hydrological characteristics of the Lower Colorado River Basin. In: Proceedings of the International Symposium on Hydrological Aspects of Mountainous Watersheds. University of Roorkee, Roorkee (UP), India, November 4–6, 1982, pp. IX-35- IX-40.**

Integrated hydrologic characteristics are presented in relation to the land-resource base and future situations with respect to water resource allocations. Future water demands will likely exceed known inputs, requiring the augmentation of water supplies.

**144. Haddad, M.S. 1990. The effects of watershed treatments on the relationship between runoff peak and volume for the Beaver Creek Watershed, Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

Relationship between runoff peak and volume is examined on watersheds in north central Arizona using least square, linear regression, and coefficient analyses to evaluate the effects of vegetation treatments.

**145. Hawkins, R.H. 1976. Runoff curve numbers for northern Arizona watersheds. Final Report Prepared by Utah State University, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Observed or realized curve numbers from watershed runoff data are determined for application to management and other decision-making matters.

**146. Li, R.M.; Simons, D.B.; Stevens, M.A. 1976. Morphology of cobble streams in small watersheds. Journal of Hydraulic Division, American Society of Civil Engineers. Vol. 102, HY8, pp. 1101–1117.**

Equations describing the basic physical processes in small watershed channels sculptured in cobble material were used in this study to derive the hydraulic geometry equations. Both downstream and at-a-station relations are developed.

**147. Reich, B.M. 1971. Runoff estimates for small rural watersheds. Final Report Prepared by Pennsylvania State University, Submitted to the Federal Highway Administration, Washington, D.C.**

Six available methods for making rapid assessments of flood peaks from small watersheds are discussed. Improved ways of blending maximum supporting information are discussed with examples from high-elevation forested watersheds in north central Arizona.

**148. Reich, B.M.; Osborn, H.B.; Baker, M.B., Jr. 1979. Tests on Arizona's new flood estimates. Hydrology and Water Resources in Arizona and the Southwest 9:65–74.**

A method for estimating regional flood frequency is used to determine how it applies to 2 clusters of small watersheds; 1 in southeastern Arizona rangeland and the other in a north central Arizona ponderosa pine forest. Results indicate that use of the generalized regional curve may underestimate flood peaks.

**149. Salvocci, G. 1990. Beaver Creek data. Final Report Prepared by Massachusetts Institute of Technology, Cambridge, Massachusetts, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A summary of climate, soil, vegetation, and hydrologic data is compiled for 3 unaltered watersheds (2, 4, and 18) in north central Arizona.

**150. Skau, C.M. 1960. Some hydrologic characteristics in the Utah juniper type of northern Arizona. PhD Dissertation, Michigan State University, East Lansing, Michigan.**

Preliminary determinations of the disposition of precipitation falling in juniper stands on the Beaver Creek Watershed is presented and the exploration of some of the factors controlling the disposition process is made.

**151. Skau. C.M. 1961. Some hydrologic influences of cabling juniper. USDA Forest Service Research Note 62.**

Information on the influences of cabling juniper in north central Arizona are reported. Pits created by cabling, and vegetation debris left on the ground help reduce the amount of surface water flow.

**152. Skau, C.M. 1964. Interception, throughfall, and stemflow in Utah and alligator juniper cover types of northern Arizona. Forest Science 10:283–287.**

Interception as related to gross precipitation and canopy density is measured for Utah and alligator juniper types in north central Arizona. A suitable equation for predicting throughfall for a range of storm sizes and vegetation densities is included.

**153. Skau. C.M.; Swanson, R.H. 1963. An improved heat pulse velocity meter as an indicator of sap speed and transpiration. Journal of Geophysical Research 68:4743–4749.**

The improved heat pulse velocity meter is stable from -50 $^{0}$ to 80 $^{0}$C. Multipoint and continuous sampling are feasible modifications. V is closely related to volume flow through stems and vapor loss from tent-enclosed trees. Effects of light, irrigation, soil drying, and leaf wetting on V agree with accepted concepts.

**154. Sulaiman, W.N. 1981. An analysis of recession flows from different vegetation types. MS Thesis, University of Arizona, Tucson, Arizona.**

Recession flows are analyzed with a set of mathematical functions to determine the most appropriate model. Differences among vegetative types are also reported.

**155. Sulaiman, W.N.; Ffolliott, P.F. 1981. An analysis of recession flows from different vegetation types. Hydrology and Water Resources in Arizona and the Southwest 11:43–46.**

A generalized mathematical model suitable for analysis of recession flows from watersheds in Arizona is presented. Constant values in the model are compared to determine significant differences.

**156. Tecle, A. 1991. Chapter 5. Hydrology and watershed management in southwestern ponderosa pine forests. In: Tecle, A. and W.W. Covington, Technical editors. 1991. Multi resource management of southwestern ponderosa pine forests: The status of knowledge. USDA Forest Service, Southwestern Region Report, pp. 162–272.**

A review of existing water-related studies in the southwestern pine type is presented. A comparison and critique of the most important models describing water yield impacts of vegetation manipulation is also included.

**157. Thorud, D.B.; Ffolliott, P.F. 1971. The 1970 Labor Day storm—a composite report. Arizona Watershed Symposium 15:46–55.**

A preliminary report of the 1970 Labor Day Storm is presented. The meteorological event, hydrological event, and estimated losses and damages are summarized. The widespread and unprecedented losses and damages caused by the storm were considered unparalleled.

**158. Thorud, D.B.; Ffolliott, P.F. 1972. The Labor Day storm of 1970 in Arizona. Western Snow Conference 40:37–42.**

A report of the 1970 Labor Day Storm is presented. The meteorological event, hydrological event, and estimated losses and damages are summarized. The losses and damages caused by the storm were considered unparalleled.

**159. Thorud, D.B.; Ffolliott, P.F. 1973. A comprehensive analysis of a major storm and associated flooding in Arizona. Arizona Agricultural Experiment Station, Technical Bulletin 202.**

A final report of the 1970 Labor Day Storm is presented. The meteorological event, hydrological event, and estimated losses and damages are summarized. The losses and damages to human, cultural, and natural resources caused by the storm were difficult to ascertain, although actual expenditures exceeded $8.2 million in the initial 18 months after the storm.

**160. Waring, R.H.; Rogers, J.J.; Swank, W.T. 1981. Water relations and hydrologic cycles. In: Dynamic Properties of Forest Ecosystems, IBP 23, Cambridge University Press. pp. 205–264.**

The 2 objectives of this chapter were to: 1) describe the processes or groups of processes affecting water movement and storage on a watershed, and 2) demonstrate the general application of the hydrologic processes by assembling them into a simulation model and applying this model to 3 extremely different forested watersheds where streamflow data were available.

## Instrumentation

**161. Baker, M.B., Jr. 1986. A supercritical flume for measuring sediment-laden streamflow. Water Resources Bulletin 22(5): 847–851.**

After 25 years of operation, this supercritical flume has provided more than 350 station-years of reliable streamflow data, even under freeze-thaw conditions at elevations of 1,500 to 2,100 m in Arizona. The flume works well where considerable sediment and other debris are expected.

**162. Brown, H.E. 1962. The canopy camera. USDA Forest Service, Research Paper RM-72.**

Development and construction of a 180-degree hemispherical camera is outlined. Potential uses of the photographs in analyzing natural resources are also discussed.

**163. Brown, H.E. 1969. A combined control-metering section for gaging large streams. Water Resources Research 5:888–894.**

A new gage design was developed to measure flow in excess of 1000 cfs, but with sufficient precision for long-term hydrologic investigations. Field ratings up to 705 cfs are presented.

**164. Brown, H.E.; Hansen, E.A.; Champagne, N.E., Jr. 1969. A system for measuring total sediment yield from small watersheds. American Geophysical Union Transactions 50:615. (Abstract)**

Abstract of Water Resources Research 6:818–826, Brown, H.E., E.A. Hansen, and N.E. Champagne, Jr. 1970. A system for measuring total sediment yield from small watersheds. Water Resources Research 6:818–826.

**165. Brown, H.E.; Hansen, E.A.; Champagne, N.E., Jr. 1970. A system for measuring total sediment yield from small watersheds. Water Resources Research 6:818–826.**

Design and calibration data are presented for sediment measuring installations using a low dam and basin to trap coarse sediments and a series of splitters that collect a portion of the suspended sediment leaving the basin. Calibration data are presented to characterize sampler performance, and a procedure is outlined for calculating total sediment yield.

**166. Brown, H.E.; Worley, D.P. 1965. Some applications of the canopy camera in forestry. Journal of Forestry 63:674–680.**

Special wide-angle photographs were used to describe a ground point in terms of the surrounding vegetation and topography. Areal extent and distribution of the canopy in relation to the photo point can be made and photos provide a means for interpreting canopy effects on direct solar radiation.

**167. Chamberlain, A.R. 1957. Preliminary model tests of a flume for measuring discharge of steep ephemeral streams. Final Report CER No. 57ARC12, Prepared by Civil Engineering Department, Colorado Agricultural and Mining College, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A number of open-channel flow measuring devices are reviewed to find one that functions satisfactorily in sedi-

ment-laden ephemeral streams on steep slopes in north central Arizona. A trapezoidal Venturi flume was selected and results of scale model tests are presented.
**168. Ffolliott, P.F. 1965. A multiple BAF angle gage. USDA Forest Service, Research Note RM-43.**

Construction of an intercept-angle gage that allows a choice of different basal area factors in point sampling is described. Biltmore and hypsometer graduations can be stamped on the gage to provide an all-purpose timber cruising instrument.

**169. Ffolliott, P.F. 1990. Manual on watershed instrumentation and measurements. ASEAN-US Watershed Management Project, College, Laguna, Philippines.**

This manual presents standards, procedures, and practices designed to minimize the major sources of error commonly associated with hydrological and climatological data sets. Quantification of rainfall, streamflow, sediment, water quality, and climate is considered.

**170. Hansen, E.A. 1966. Field test of an automatic suspended-sediment pumping sampler. Transactions American Society of Agricultural Engineers 9:738–741, 743.**

An individual-sample bottling system is described that is portable and operational on perennial or ephemeral streams with either ac or dc electricity. Concentration of sediments at the lower intake was close to the average that in the vertical over the range of discharges and concentrations sampled.

**171. Larson, F.R. 1974. Formulating conversion tables for stick-measure of Sacramento precipitation storage gages. USDA Forest Service, Research Note RM-276.**

These gages are usually built to specifications by local sheet metal companies where quality control is limited. Mathematical models for estimating precipitation in constructed gages are presented and calibration techniques are described.

**172. Pearson, H.A.; Morrison, D.C.; Wolke, W.K. 1969. Trick tanks: Water developments for range livestock. Journal of Range Management 22:359–360.**

Trick tanks with large rain collectors may provide water for livestock at half the cost of hauling, with the added benefit of shelter.

**173. Robinson, A.R. 1959. Trapezoidal measuring flumes for determining discharge in steep ephemeral streams. Final Report CER59ARR1 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Correlations of model flume studies and field measurements are presented and recommendations relative to future field measurements and general operation of the flumes are made.

**174. Robinson, A.R. 1960. Model study of a trapezoidal flume for measurement of stream discharge. Final Report CER59AR57 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Results of 1:6 scale model test are presented and cover effects of slope of the structure, upstream approach geometry, degree of roughness in the upstream channel, deposits of material in the structure, use of complete and modified flume construction, and downstream submergences.

**175. Robinson, A.R. 1961. Study of the Beaver Creek measuring flumes. Final Report CER61ARR10 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Results of a 1:2 scale model study and analyses of additional field measurements are presented. A standard rating curve developed using all available data is presented.

**176. Robinson, A.R.; Chamberlain, A.R. 1958. Trapezoidal flumes for open channel flow measurement. Final Report CER58ARR39 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Findings of a research and development program concerned with trapezoidal flumes conducted in the Colorado State University Hydraulics Laboratory are discussed. A review of past work on measuring flumes in general and on trapezoidal flumes in particular are presented.

**177. Robinson, A.R.; Chamberlain, A.R. 1960. Trapezoidal flumes for open channel flow measurement. Transactions of American Society Agricultural Engineers 3:120–128.**

Findings of a research and development program concerned with trapezoidal flumes conducted in the Colorado State University Hydraulics Laboratory are discussed. A review of past work on measuring flumes in general and on trapezoidal flumes in particular are presented.

## Inventory Methods

**178. Barger, R.L.; Ffolliott, P.F. 1969. Multiproduct timber inventory. Forest Products Journal 19:31–36.**

The timber inventory described recognizes and measures the basic stem characteristics and defect features influencing quantity and quality for most primary products. Timber inventory data obtained are used in conjunction with standard methods of volume estimation, scaling, and grading.

**179. Barger, R.L.; Ffolliott, P.F. 1969. Multiproduct timber inventory. In: 21st Annual Meeting of the Forest Products Research Society, July, 1967, Vancouver, British Columbia, Canada.**

An inventory system is described that attempts to characterize timber quality and the suitability of standing timber for a wide variety of primary products.

**180. Barger, R.L.; Ffolliott, P.F. 1970. Evaluating product potential in standing timber. USDA Forest Service, Research Paper RM-57.**

The timber inventory described recognizes and measures the basic stem characteristics and defect features influencing quantity and quality for most primary products. Stem features measured on sample trees include form defects, scar defects, and know or limb characteristics. Estimates of volume suitable for a primary product and quality of the timber in terms of existing grading or quality classification systems are also obtained.

**181. Clary, W.P. 1964. A method for predicting potential herbage yield on the Beaver Creek pilot watersheds. In: Forage Plant Physiology and Soil-Range Relationships. American Society of Agronomy. ASA Special Publication 5:244–250.**

Soil sampling units are used with some success to predict site quality of grassland communities. The importance of working within geographic conditions is stressed.

**182. Clary, W.P. 1969. Increasing sampling precision for some herbage variables through knowledge of the timber overstory. Journal of Range Management 22:200–201.**

Precision of estimates for herbaceous understory can be doubled by using auxiliary information about timber overstory to obtain a regression estimate. Estimate improvements can be made in total herbage production, total perennial grass production, and total forage consumed.

**183. Ffolliott, P.F. 1965. Determining growth of ponderosa pine in Arizona by stand projection. USDA Forest Service, Research Note RM-52.**

A procedure for estimating the growth rates from 1 sampling of a forest by applying a stand table projection method is described. A stand table of growing stock, average annual rates of diameter growth, and height measurements to adjust volume tables are required to apply the method. Sampling intensities are presented to assist in designing inventories to collect the necessary information.

**184. Ffolliott, P.F. 1978. A multifunctional inventory approach to multiple use analysis. In: Lund, H.G., V.J. LaBau, P.F. Ffolliott, and D.W. Robinson, editors. Proceedings, Integrated Inventories of Renewable Natural Resources. USDA Forest Service, General Technical Report RM-55, pp. 395–402.**

A multifunctional inventory synthesized for multiple-use evaluations through application of relevant research findings is described. Relationships between natural resource products and uses that are difficult to measure and direct measurements for forest overstory characteristics, which can be relatively easy to obtain through standard mensuration procedures, are highlighted.

**185. Ffolliott, P.F.; Barger, R.L. 1965. A method of evaluating multiproduct potential in standing timber. USDA Forest Service, Research Paper RM-15.**

The method described will remove observer bias from stand quality inventories; provide a record of frequencies of occurrence of stem features that affect product quality and yield; characterize and quantify suitability of the timber resource for a broad range of products; furnish adequate multiproduct quality and yield information for management and decision making; and provide a continuing basis for such decisions through time.

**186. Ffolliott, P.F.; Barger, R.L. 1971. New approach to estimating timber products. Progressive Agriculture in Arizona 23:11–13.**

A timber inventory is presented to identify and measure basic stem characteristics in standing trees. The information obtained was interpreted in terms of basic product requirements and present grading and quality classification systems to estimate suitability of the timber for a variety of primary products.

**187. Ffolliott, P.F.; Worley, D.P. 1965. An inventory system for multiple use evaluations. USDA Forest Service, Research Paper RM-17.**

A multiple basal area factor inventory that is flexible enough to describe a forest so multiple-use interpretations can be made from known relations of product yields to the inventory description of resources on the tract is presented. Basal area was selected as the inventory basis because it is easily determined in the field, easily converts to other expressions, and many multiple-use relations have already been developed with basal area as the independent variable. Basal area use is illustrated by hypothesizing forest management methods for a watershed in north central Arizona.

**188. Ffolliott, P.F.; Worley, D.P. 1973. Forest stocking equations: Their development and application. USDA Forest Service, Research Paper RM-102.**

Equations relating proportions of a forest stocked to minimum basal area levels can be defined by regression analysis. Equations can be used to help evaluate land treatment potential, determine treatment feasibility, and set operating priorities.

**189. Garrett, L.D. 1982. Interdisciplinary research for Multi resource forest management: an example. In: Russel, M.G., editor. Enabling interdisciplinary research: perspectives from agriculture, forestry, and home economics. University of Minnesota Agricultural Experiment Station Miscellaneous Publication 19, pp. 147–152.**

Multi-resource management research in Southwestern ponderosa pine and pinyon-juniper types is attempting to provide management guidelines using multi-resource inventory, analysis, modeling, and user interaction. Descriptions are provided for inventories and data base management systems being used and for a model of the land-management planning process being tested.

**190. Garrett, L.D. 1983. Multi resource research and its implications to management: the Beaver Creek Biosphere Reserve. In: Patton, D.R., et al., technical coordinators. Wildlife and range research needs in northern Mexico and southwestern United States, workshop proceedings, USDA Forest Service General Technical Report WO-36, pp. 40–44.**

This research project was designed to create management guidelines using integrated multi-resource inventory and analysis techniques. Interim evaluations of multi-resource responses to management treatments in ponderosa pine and pinyon-juniper types have been completed. Results are described that include single and multi-resource treatment responses and analytical models.

**191. Garrett, L.D.; Rogers, J.J.; Prosser, J.M. 1982. Multi resource inventory and analysis system: Gaining maximum benefit for land managers. In: Brann, F.B., L.O. House, IV, H.G. Lund, editors, In: Place resource inventories: principles and practices, Proceedings of a national workshop, Orono, Maine, August 9–14, 1981, Society of American Foresters, pp. 1011–1017.**

Multi-resource management research in Southwestern ponderosa pine and pinyon-juniper types is attempting to provide management guidelines using multi-resource inventory, analysis, modeling, and user interaction. Descriptions are provided for inventories and data base management systems being used and for a model of the land-management planning process being tested.

**192. Ilch, D.M. 1967. Researchers also contribute to management improvement. USDA Forest Service, Division of Administrative Management, Management Notes 19, pp. 17–19.**

Some improvement ideas are detailed, complex procedures designed to yield better information for decision making. An example is the inventory system developed for making multiple-use evaluations on Beaver Creek watersheds.

**193. Larson, F.R.; Minor, C.O. 1968. A comparison of stand density measurements for ponderosa pine in the Southwest. Arizona Forestry Notes No. 4, School of Forestry, Northern Arizona University.**

Comparisons of expressions of stand density for even-aged young-growth pine stands are made and preferred expressions best related to growth rate are identified.

**194. Larson, F.R.; Moessner, K.E.; Ffolliott, P.F. 1971. A comparison of aerial photo and ground measurements of ponderosa pine stands. USDA Forest Service, Research Note RM-192.**

Ground estimates of cubic-foot volume and basal area were significantly correlated with photo estimates. Differences in results due to plot size (1/5 or 1 acre) or photo scale (1:15,840, 1:6,000, or 1:3,000) were minor. The 1/5-acre plots on 1:6,000 scale tested were the most efficient to measure, however.

**195. Larson, F.R.; Ffolliott, P.F.; Moessner, K.E. 1974. Using aerial measurements of forest overstory and topography to estimate peak snowpack. USDA Forest Service, Research Note RM-267.**

Where slope steepness and aspect vary widely and forest overstory size and density classes are intermixed, only topographic attributes need to be measured. On nearly level sites with homogeneous size and density classes, forest overstory attributes must be measured. All tested photo scales were satisfactory.

**196. Lund, H.G.; LaBau, V.J.; Ffolliott, P.F.; Robinson, D.W. technical coordinators. 1978. Integrated inventories of renewable natural resources: Proceedings of the workshop. USDA Forest Service, General Technical Report RM-55.**

The purpose of the workshop was to promote efficient, objective, and timely inventory systems through integrated inventories. Topics covered included information requirements, the need for integrating inventories, land classification systems, remote sensing, data processing, and information systems.

**197. Senn, R.A., Jr. 1976. A descriptive inventory of ponderosa pine on national forests in the Salt-Verde Basin, Arizona. USDA Forest Service General Technical Report RM-26.**

Inventories of ponderosa pine forests are described in terms of distribution, density, and productivity.

**198. Worley, D.P. 1966. A forest inventory approach to multiple use analysis. Society American Foresters 1966:138–142.**

Results of studies on watersheds in north central Arizona show that an inventory can be designed for estimating multiple-use product responses to various management alternatives. Estimates can be used as a basis for selecting alternative management options or for multiple-use coordination.

## Modeling

**199. Baker, M.B., Jr. 1975. Modeling management of ponderosa pine forest resources. In: Proceedings of the 1975 watershed management symposium, Logan, Utah, August 11–13, American Society of Civil Engineers, Irrigation and Drainage Division, pp. 478–493.**

Manipulating forest on volcanic soils in Arizona showed that: water yield increases of 0.6 inch are realistic; harvestable timber growth can be increased, even with reduced basal area; understory plant growth and deer and elk habitat can be improved; and economic returns can be increased, even when environmental factors are emphasized.

**200. Baker, M.B., Jr.; Carder, D.R. 1976. An approach for evaluating water yield and soil loss models. Earth Sciences Symposium Proceedings, Fresno, California.**

State-of-the-art models are identified and procedures for comparatively testing these models are described. Information is useful in judging or selecting which models best meet user needs considering specific decision-making situations and constraints.

**201. Baker, M.B., Jr.; Rogers, J.J. 1983. Evaluations of water balance models on a mixed conifer watershed. Water Resource Research 19:486–492.**

Three models of differing degrees of complexity were evaluated using data from a mixed conifer watershed in east central Arizona. Evaluations provide information that help managers judge which models, if any, are most suited to their needs.

**202. Bojorquez-Tapia, L.A. 1987. Multiple-resource modelling in the forest and woodland ecosystems of Arizona. PhD Dissertation, University of Arizona, Tucson, Arizona.**

Modifications of available models are described. Applications are presented to illustrate their usefulness to managers and decision makers. The potential for application in Mexico is also discussed.

**203. Bojorquez-Tapia, L.A.; Ffolliott, P.F.; Guertin, D.P. 1990. Multiple-resource modeling as a tool for conservation: Its applicability in Mexico. Environmental Management 14:317–324.**

The use of multiple-resource modeling in land-use planning and environmental assessment is proposed. Applications of MICROSIM, a set of modeling software for microcomputers, in the montane forests of northwestern Mexico are illustrated.

**204. Brown, T.C.; Daniel, T.C. 1984. Modeling forest scenic beauty: concepts and application to ponderosa pine. USDA Forest Service Research Paper RM-256.**

Models relate near-view scenic beauty of pine stands in the Southwest to variables describing physical characteristics. Models suggest that herbage and large pine trees contribute to scenic beauty, while numbers of small and intermediate-sized trees and downed wood detract from scenic beauty. Areas of lower overstory density and less tree clumping were preferred.

**205. Clary, W.P.; Jensen, C.E. 1981. Mathematical hypothesis for herbage production potential on pinyon-juniper areas. USDA Forest Service Research Paper INT-279.**

A theorized form of the relation between potential herbage production and annual precipitation, original tree cover, soil nitrification level, and presence or absence of limestone soil is developed and tested on a small data set from north central Arizona.

**206. Ffolliott, P.F. 1985. Application of multiple-resource modeling in watershed management. Working Paper for the International Center for Integrated Mountain Development, Kathmandu, Nepal.**

A group of computer simulation models developed for application in the Southwestern United States is described. The procedure for extrapolating the framework of the models elsewhere is also presented.

**207. Ffolliott, P.F.; Guertin, D.P.; Rasmussen, W.O. 1988. A model of snowpack dynamics in forest openings. Hydrology and Water Resources in Arizona and the Southwest 18:1–6.**

Formulation and application of a model to estimate the impacts of creating forest openings on snowpack dynamics are described. The model links to another model that depicts snowpack changes following reductions in forest densities by thinning.

**208. Gabbert, W.A. 1982. Simulation of nutrient and heavy metal transport capacity of suspended sediment. MS Thesis, University of Arizona, Tucson, Arizona.**

A computer simulation model is presented to estimate the impacts of alternative land-management practices on nutrient and heavy metal losses in transported sediments from forested watersheds including representative Beaver Creek watersheds. Geology and vegetation are the primary predictors of the concentrations of chemical constituents.

**209. Gabbert, W.A.; Ffolliott, P.F.; Rasmussen, W.O. 1982. SEDCON: A model of nutrient and heavy metal losses in suspended sediment. Hydrology and Water Resources in Arizona and the Southwest 12:111–116.**

A model to predict acid-digestible and extractive nutrients in suspended sediments is described. Knowledge of forest types and geology is necessary to interrogate the model.

**210. Gieske, M.H.; Boster, R.S. 1971. DAMID, A discounting analysis model for investment decisions. USDA Forest Service Research Note RM-200.**

A computer program discounts benefit and cost flows over time for up to 10 user- determined interest rates and permits combining flows of differing lengths. Outputs include discounted values of individual costs or benefits, a summed net present value for and an entire project, and interpolated values for without available data.

**211. Heidt, J.D.; Jameson, D.A.; Barger, R.L.; Erickson, B.J. 1971. Determining timber conversion alternatives through computer analysis. USDA Forest Service, Research Paper RM-74.**

Computer program MULTI accepts basic field inventory data, calculates gross board-foot and cubic-foot volumes, grades or classifies for a number of specified primary products, adjusts gross volume for visual defects, and calculates standard error. Output tables independently give adjusted net volume per acre and by grade and size class for each product.

**212. Jasinski, M.F. 1989. Physically-based parameterization of spatially variable soil and vegetation using satellite multispectral data for mesoscale hydrology. DS Dissertation, Massachusetts Institute of Technology, Cambridge, Massachusetts.**

Efforts to formulate and test a physically-based reflectance model that characterizes the spatial variability of multispectral images obtained over semi-vegetated landscapes are reported. Several sites on Beaver Creek watershed were used in this study.

**213. Larson, F.R.; Ffolliott, P.F.; Rasmussen, W.O.; Carder, D.R. 1979. Estimating impacts of silvicultural management practices on forest ecosystems. In: Best Management Practices for Agriculture and Silviculture, Proceedings of the 1978 Cornell Agriculture Waste Management Conference, pp. 281–294.**

A prototype family of computer simulation models, called ECOSIM, is being developed to help forest managers and land-use planners estimate the impact of silviculture on forest ecosystems.

**214. Li, R.M.; Carder, D.R.; Simons, D.B.; Shiao, L.Y. 1977. Mathematical modeling of sediment yield from forest logging roads. In: Proceedings of First International Conference on Mathematical Modeling, St. Louis, MO.**

A guide is presented for assessing relative quantities of sediment yield from surface erosion on roads when considering alternative route locations, cross-section road gradients, surface type, and cross-drain spacing. This method is useful in selecting the design alternative that produces the least sediment rather than determining how much sediment will be produced.

**215. Li, R.M.; Simons, D.B.; Carder, D.R. 1976a. Mathematical modeling of overland flow soil erosion. In:**

**Natural Soil Erosion Conference: Prediction and Control, May 25–26. Soil Conservation Society of America, Special Publication No. 21.**

An unsteady, overland-flow soil-erosion model was developed to simulate sediment outflow hydrographs and land form evolution processes on a sandy soil surface.

**216. Li, R.M.; Simons, D.B.; Eggert, K.G. 1976. Process model of infiltration and subsurface flow routing. Final Report CER76-77 RML-DBS-KGE 20 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A simple infiltration model considering unsteady rainfall is presented and combines the predictive advantages of a nonlinear, physically-based approach with the classical tabular method for estimating available runoff from rain. A subsurface flow-routing model was also developed based on the Green-Ampt infiltration scheme and a simple finite difference formulation of the Dupuit approximation. The scheme is unconditionally stable and suitable for inclusion in a more complex watershed model.

**217. Li, R.M.; Simons, D.B.; Simons, R.K. 1977. A mathematical model for evaluating on-site soil erosion. Final Report CER76-77 RML-DBS-RKS 40 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

An unsteady, overland-flow soil-erosion model is presented. The model simulates water and sediment outflow hydrographs and considers the physical processes of interception, infiltration, and soil detachment by raindrop splash and surface runoff. Routing of water and sediment is accomplished by using a 4-point implicit formulation of the kinematic approximation.

**218. Li, R.M.; Simons, D.B.; Stevens, M.A. 1973. Review of literature: Cooperative study on development of models for predicting sediment yield from small watersheds. Final Report CER72-73RNL-DBS-MAS14 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A review was made to determine the best methodology to use when developing models for estimating sediment yields from a broad spectrum of watersheds including sediment routing through the channel system.

**219. Li, R.M.; Simons, D.B.; M.A. Stevens, M.A. 1975. On overland flow water routing. In: Proceedings of the National Symposium on Urban Hydrology and Sediment Control [Univ. of Kentucky, Lexington, July 28–31.**

A generalized, analytical solution to the kinematic wave approximation was developed to route overland flow with time-variant but spatially uniform rainfall.

**220. Li, R.M.; Simons, D.B.; Stevens, M.A. 1976. Morphology of cobble streams in small watersheds. Journal of Hydraulic Division, American Society of Civil Engineers. Vol. 102, HY8, pp. 1101–1117.**

As an extension of previous work on stable channel designs, the basic equations describing threshold channel shape were used to derive the hydraulic geometry equations of a stream in coarse alluvium. Both downstream and at-a-station relationships were developed. Theoretical results agreed with field observations.

**221. Li, R.M.; Simons, D.B.; Ward, T.J.; Orvis, C.J. 1979. Hydraulic model study of flow control structures. Final Report CER78-79RML-DBS-TJW-CJ051 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Results of laboratory studies on steep channel (5 to 25% bed slope) and gravel-bed sediment transport indicated that a form of Meyer-Peter Muller sediment-transport equation is applicable for steep, gravel-bed streams. However, the coefficients should be calibrated using measured data.

**222. Li, R.M.; Simons, D.B.; Ward, T.J.; Steele, K.S. 1977. Hydraulic model study of flow control structures. Final Report CER 77-78 RML-DBS-TJW-KSS 15 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Results of laboratory studies on steep channel (5 to 25% bed slope) and gravel-bed sediment transport indicate that a form of Meyer-Peter Muller sediment-transport equation is applicable for steep, gravel-bed streams. However, the coefficients should be calibrated using measured data.

**223. Lopes, V.L.; Ffolliott, P.F. 1992. Modeling sediment processes on small watersheds: A conceptual framework. I. Broad shallow flow processes. International Journal of Sediment Research 7:21–44.**

A conceptual modeling framework for developing process-based mathematical models of sediment generation, transport, and deposition on broad, shallow flow areas is presented. This framework applies to hydrologic conditions represented by the Beaver Creek watersheds.

**224. Lopes, V.L.; Ffolliott, P.F. 1993a. A conceptual framework for modeling sediment processes in upland watersheds. In: Pre-Conference Proceedings of the International Conference on Hydrology and Water Resources, New Delhi, India, December 20–22, 1993, pp. 59. (Abstract)**

A modeling framework is presented as a basis for developing numerical models of sediment processes on upland watersheds. Sediment processes are described in terms of broad and shallow flow areas and concentrated flow systems. Basic assumptions and governing equations are presented.

**225. Lopes, V.L.; Ffolliott, P.F. 1993b. Modeling sediment processes on small watersheds: A conceptual framework. II. Concentrated flow processes. International Journal of Sediment Research 8:1–23.**

A conceptual modeling framework is presented for developing sediment process models by concentrated flow systems on small watersheds. This framework applies to hydrologic conditions represented by Beaver Creek watersheds.

**226. Lovely, C.J. 1976. Hydrologic modeling to determine the effect of small earthen reservoirs on ephemeral streamflow. MS Thesis, University of Arizona, Tucson, Arizona.**

The USDAHL-74 model was used to simulate effects of small water reservoirs on streamflow in north central Arizona. Winter and spring runoff was reduced 2.6 to 10.7% for the 4 years studied.

**227. McGurk, B.J. 1982. A comparison of four rainfall-runoff methods. PhD Dissertation, Utah State University, Logan, Utah.**

The relative accuracies of 4 models to predict runoff volume from watersheds in the United States Intermountain region are compared.

**228. O'Connell, P.F. 1970. Economic modelling in natural resource planning. Arizona Watershed Symposium Proceedings 14:31–38.**

The role economics can play in putting multiple-use principles into practice on national forest land is discussed.

**229. Reich, B.M. 1971. Feasibility study of conceptual models for Beaver Creek hydrology. Final Report Prepared by Pennsylvania State University, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Using hydrologic models in the Beaver Creek studies will permit extrapolation of the research results to different soils and climate. This report mentions several models for possible testing on Beaver Creek after some modifications.

**230. Simons, D.B.; Li, R.M. 1975. Watershed segmentation by a digital computer for mathematical modeling of watershed response. Final Report CER75-76DBS-RML9 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A model to segment a watershed into overland flow and channel units is presented. An additional program was developed to combine small grid units into larger response units. Flow is routed from overland flow units to channel units and then to the selected watershed outlet.

**231. Simons, D.B.; Li, R.M. 1976. Procedure for estimating model parameters of a mathematical model. Final Report CER75-76DBS-RML22 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Systematic and reliable methods for estimating model parameters are reviewed and recommendations are presented.

**232. Simons, D.B.; Li, R.M. 1977. In-field estimation of infiltration parameters. Report Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Procedures from estimating infiltration parameters are presented. The recommended techniques were applied on the Beaver Creek watershed in north central Arizona.

**233. Simons, D.B.; Li, R.M. 1980. Modeling of sediment nonpoint source pollution from watersheds. In: Overcash, M.R., and J.M. Davidson, editors. Environmental impact of nonpoint source pollution. pp. 341–373.**

Various models developed at Colorado State University for estimating sediment yield from watersheds are discussed; physical process simulation models are emphasized. Models account for physical processes of raindrop splash, overland flow erosion, channel erosion, and movement of different sediment size fractions.

**234. Simons, D.B.; Carder, D.R.; Li, R.M. 1977. Principle and application of mathematical modeling of watershed and river systems. In: Proceedings of the First International Conference on Mathematical Modeling. [St. Louis, MO.**

Various principles used in modeling watershed and river system responses are reviewed. Applications of these modeling techniques is also presented.

**235. Simons, D.B.; Li, R.M.; Eggert, K.G. 1977a. Simple water routing and yield model using a small programmable calculator. Final Report CER76-77-DBS-RML-KGE52 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A simple watershed model is developed based on physical rather than empirical principles for use in a small, programmable calculator.

**236. Simons, D.B.; Li, R.M.; Eggert, K.G.; Zachmann, D. 1981. Quasi-analytical formulation for calculation of infiltration and runoff. Final Report Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Efficient methods for predicting catchment runoff are presented. Cost efficiency is obtained by employing analytical and quasi-analytical solution techniques. The solutions developed are modular and can easily be interfaced with each other or with existing watershed models.

**237. Simons, D.B.; Li, R.M.; Shiao, L.Y. 1976. Preliminary procedural guide for estimating water and sediment yield from roads in forests. Final Report CER76-77DBS-RML-LYS21 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A guide is presented for assessing the relative quantities of sediment from surface erosion on roads considering alternative route locations, cross-section road gradients, surface type, and cross-drain spacing. This method is useful in when selecting the design alternative that produces the least amount of sediment rather than determining how much sediment will be produced.

**238. Simons, D.B.; Li, R.M.; Shiao, L.Y. 1977. Formulation of road sediment model. Final Report CER76-77DBS-RML-LYS50 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Formulation of a physical process model that simulates surface erosion from roads is presented. Many processes in this model are similar to those in a watershed surface erosion model. The model was tested using limited, onsite soil erosion data.

**239. Simons, D.B.; Li, R.M.; Stevens, M.A. 1975. Development of models for predicting water and sediment routing and yield from storms on small watersheds. Final Report CER74-75DBS-RML-MAS24 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Prediction models were developed to estimate water and sediment yields from a broad spectrum of source areas and watersheds. These models were tested on study areas within the Beaver Creek drainage and on watersheds in other parts of the United States having different climates, soils, and vegetation.

**240. Simons, D.B.; Li, R.M.; Ward, T.J. 1977. Simple procedural method for estimating onsite soil erosion. Final Report CER76-77RML-DBS-TJW38 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A simple procedure for evaluating erosion rates based on classification of storm size, soil characteristics, and vegetation cover densities is presented. The model was tested using a numerical model and field data.

**241. Simons, D.B.; Li, R.M.; Ward, T.J. 1978a. Estimation of parameters that describe channel geometry for watershed modeling. Final Report CER77-78DBS-RML-TJW12 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A methodology is presented for estimating important channel geometry parameters. The recommended field techniques are applicable to ephemeral streams but may not be useful for some perennial channels. The test area was the Beaver Creek drainage in north central Arizona.

**242. Simons, D.B.; Li, R.M.; Ward, T.J. 1978b. Equation and computer programs that develop design tables for estimating road sediment yield. Final Report CER77-78DBS-RML-TJW40 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Equations used to generated design values to assess sediment yield from forest roads are presented. These equations, based on physical processes, provide a realistic alternative to existing regression-type equations, particularly when assessing impacts resulting from natural or man-made alterations.

**243. Simons, D.B.; Li, R.M.; Ward, T.J. 1978c. Mapping of potential landslide areas in terms of slope stability. Final Report CER78-79DBS-RML-TJW19 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Methods for estimating landslide potential and probability are presented. Since it is impossible to assign every factor a single value, uncertainty and the possibility that a combination of factors will occur must be considered.

**244. Simons, D.B.; Li, R.M.; Ward, T.J. 1980. Application of road sediment models to natural and simulated rainfall-runoff sites. Final Report CER79-80DBS-RML-TJW66 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Results of application of 2 road-sediment models is presented. Model results matched measured results reasonably well. Application of the simplified model to simulated rainfall was very good because of better control provided by the experimental procedure.

**245. Simons, D.B., R.M. Li, and T.J. Ward. 1981. Analysis of data collection and processing system for Beaver Creek Watershed, Arizona. Final Report CER79-80DBS-RML-TJW68 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The data collection system on Beaver Creek is large and complicated, however, the quantity and quality appears to be good. Suggestions for improving the system are presented.

**246. Simons, D.B.; Li, R.M.; Ward, T.J.; Ballantine, M. 1980. Methodology for estimating erosion rates and sediment yields for lead forest land management alternatives. Final Report Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A model is presented that estimates annual sediment yields by particle size fraction. A test of the model using a watershed on the Arapaho and Roosevelt National Forests is also provided.

**247. Simons, D.B.; Li, R.M.; Ward, T.J.; Ballantine, M. 1981. User's guide for providing model input information for a generalized land planning model. Final Report CER80-81DBS-RML-TJW-MJB40 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A unified procedure on data preparation techniques for the generalized land-use model is supplied and demonstrated using a step-by-step approach for a hypothetical watershed.

**248. Simons, D.B.; Li, R.M.; Ward, T.J.; Shiao, L.Y. 1978. Simple road sediment yield model. Final Report CER77-78DBS-RML-TJW-LYS41 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The theory and formulation of a mathematical model to estimate water and sediment yield from roadways is presented. Model applicability is tested with erosion plot data. In addition, using the model for evaluating various roadway design factors is demonstrated.

## Multi-resource Management

**249. Baker, M.B., Jr.; Brown, H.E. 1974. Multiple use evaluations on ponderosa pine forest land. Arizona Watershed Symposium Proceedings 18:18–25.**

A resume of USDA Forest Service Research Paper RM-129 by Brown, H.E., M.B. Baker, Jr., J.J. Rogers, W.P. Clary, J.L. Kovner, F.R. Larson, C.C. Avery, and R.E. Campbell 1974, is presented (see below). Opportunities for increasing water yields and other multiple-use values in ponderosa pine forests are discussed.

**250. Brown, H.E. 1965. Preliminary results of cabling Utah juniper, Beaver Creek watershed evaluation project. Arizona Watershed Symposium Proceedings 9:16–20.**

The cabling treatment of a juniper watershed in north central Arizona is described along with its affect on various watershed products.

**251. Brown, H.E.; Baker, M.B., Jr.; Rogers, J.J.; Clary, W.P.; Kovner, J.L.; Larson, F.R.; Avery, C.C; Campbell, R.E. 1974. Opportunities for increasing water yields and other multiple use values on ponderosa pine forest lands. USDA Forest Service, Research Paper RM-129.**

Multiple-use productivity is described, with special emphasis on the Beaver Creek watershed in north central Arizona. Changes in productivity and environmental quality are described following livestock grazing and various levels of forest thinning and clearing. Preliminary analytical procedures allow the user to estimate the tradeoffs in production and environmental quality.

**252. Clary, W.P. 1974. Pinyon-juniper control—does it pay? Arizona Watershed Symposium Proceedings 18: 26–29.**

A resume of USDA Forest Service Research Paper RM-128 by Clary, W.P., M.B. Baker, Jr., P.F. O'Connell, T.N. Johnsen, Jr., and R.E. Campbell 1974, is presented (see below). Effects of pinyon-juniper removal on natural resource products and uses in Arizona are considered.

**253. Clary, W.P. 1975a. Present and future multiple use demands on the pinyon- juniper type. In: The pinyon-juniper ecosystem: A symposium, Utah State University, Logan, Utah, pp. 19–26.**

Because of increasing pressures for livestock grazing, wildlife, and wood products, optimum management should result in a shifting mosaic of activities, with each site managed for the product or product mix for which it is best suited.

**254. Clary, W.P. 1975b. Multiple use effects of manipulating pinyon-juniper. In: Proceedings of the 1975 watershed management symposium, Logan, Utah, American Society of Civil Engineers, Irrigation and Drainage Division, pp. 469–477.**

Mechanical methods of pinyon-juniper removal are unlikely to increase water-yields; herbicidal treatment may. Herbage yields increase after all treatments; deer response is generally neutral. The more successful conversion projects neither make nor lose money.

**255. Clary, W.P. 1977. Producer-consumer biomass on forested and nonforested Arizona fescue range. Abstract of Papers, 30th Annual Meeting, Society for Range Management, Portland, Oregon, p. 9.**

Investigations in north central Arizona that illustrate differences in plant and animal biomass on forested and nonforested fescue range are presented.

**256. Clary, W.P. 1978. Producer-consumer biomass in Arizona ponderosa pine. USDA Forest Service, General Technical Report RM-56.**

Managed ponderosa pine forests in central Arizona support above-ground biomass of approximately 60,000 to 80,000 kg/ha. Consumer biomass is only about 8 to 12 kg/ha. Livestock dominate, followed by elk, deer, insects, and small mammals. Forest openings have much less green foliage than the forest but support 3 to 5 times the herbivore biomass per hectare because of the dominance of herbaceous plants.

**257. Clary, W.P. 1987. Herbage production and livestock grazing on pinyon- juniper woodlands. In: Everett, R.L., compiler, Proceedings of the Pinyon-juniper Conference, January 13–16, 1986, Reno, Nevada. USDA Forest Service General Technical Report INT-215. pp. 440–447.**

Broad comparisons of published data suggest that grazed plant communities may have substantially less herbage production than ungrazed. Continuous season-long grazing at proper stocking rates appears to produce the heaviest calf weights in summer rainfall areas, but no information is available from other parts of the woodlands.

**258. Clary, W.P.; Baker, M.B., Jr.; O'Connell, P.F.; Johnsen, T.N., Jr.; Campbell, R.E. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. USDA Forest Service, Research Paper RM-128.**

Results of pilot treatments to increase water and forage yields by removing pinyon-juniper trees are presented. Herbicide treatments were more effective than mechanical removal of trees, but even on the more productive sites, costs and benefits were about even. Affects on other resources are about neutral.

**259. Clary, W. P.; Ffolliott, P.F.; Larson, F.R. 1984. Producer-consumer biomass in montane forests on the Arizona Mogollon Plateau. The Great Basin Naturalist 44:627–634.**

A compilation of producer-consumer biomass is presented for 2 forest stands. Ponderosa pine dominated stands appeared to be near the lower end of the biomass range of commercial forest types.

**260. Clary, W.P.; Kruse, W.H.; Larson, F.R. 1975. Cattle grazing and wood production under different ponderosa pine basal areas. Journal of Range Management 28:434–437.**

Beef gain potential was maximum at zero basal area and was one-third less when ponderosa pine was present at basal areas of 20 $ft^2$/acre. The combined economic value of grazing and saw-log production would be maximum in stands having a basal area of about 45 to 60 $ft^2$/acre.

**261. Ffolliott, P.F. 1980. UNESCO's Man and the Biosphere Program: Interdisciplinary and international col-**

**laboration on environmental research in temperate forests. The 140th National Meeting of the American Association for the Advancement of Science, San Francisco, California, January 3– 8, 1980, AAAS Publication 80-2, p. 33. (Abstract)**

Research of Man and the Biosphere Project II are reviewed. International activities include binational studies on La Michilia and the Beaver Creek Biosphere Reserves.

**262. Ffolliott, P.F. 1983a. Moderator's comments: Research on biosphere reserves. In: Patton, D.R., J. de la Puente-E., P.F. Ffolliott, S. Gallina, and E.T. Bartlett, technical coordinators. Wildlife and range research needs in northern Mexico and southwestern United States: Workshop proceedings. USDA Forest Service, General Technical Report WO-36, pp. 32–33.**

Research possibilities on biosphere reserves throughout the world in general, and on the Beaver Creek and La Michilia Biosphere Reserves in particular are identified. Examples of collaborative research activities on the latter biosphere reserves are also presented.

**263. Ffolliott, P. F. 1983b. Multi resource management on the Beaver Creek Biosphere Reserve, United States. Program on the Man and the Biosphere (MAB), Newsletter for Project 2 5:11–15.**

The Multi resource management program on Beaver Creek serves the people of the Southwestern United States. Many of the planning methods and results are designed to be useful to managers throughout the United States and elsewhere.

**264. Ffolliott, P.F. 1992. Multiple values of woodlands in the southwestern United States and northern Mexico. In: Ffolliott, P.F., G.J. Gottfried, D.A. Bennett, V.M. Hernandez, A. Ortega-Rubio, and R.H. Hamre, technical coordinators. Ecology and management of oak and associated woodlands: Perspectives in the southwestern United States and northern Mexico. USDA Forest Service, General Technical Report RM-218, pp. 17–23.**

Silvicultural characteristics of tree species, wood products, livestock production, wildlife resources, watershed management, and recreation and tourism are reviewed. A land-use history and current multiple-use perspective is presented.

**265. Ffolliott, P.F.; Baker, M.B., Jr. 1977. Characteristics of Arizona ponderosa pine stands on sandstone soils. USDA Forest Service, General Technical Report RM-44.**

Physiographic, hydrologic, and biotic characteristics are described. General comparisons are also made between these characteristics and those for ponderosa pine forests on volcanic soils.

**266. Ffolliott, P.F.; Bartlett, E.T. 1991. Dry forests of North America: Opportunities for multiple use resource management. In: Ffolliott, P.F., and W.T. Swank, eds. People and the temperate region: A summary of research from the United States Man and the Biosphere Program. U.S. Department of State, Publication 9838, pp. 41–44.**

Research and educational focus of the binational USA-Mexico program is presented in terms of accomplishments attained. Management implications of the research findings of both countries are discussed.

**267. Ffolliott, P.F.; Brooks, K.N. 1985. Forest resources: Multiple use concept. In: Report of the FAO/Finland Training Course in Forestry and Watershed Management for Asia and the Pacific Region, Katmandu, Nepal, May 19–31, 1985. FAO, Rome Italy, pp. 81–87.**

The multiple-use concept suggests that forest management decisions should not be restricted to wood products but should also consider food, water, forage, and wildlife. Application of this concept on the Beaver Creek watersheds is presented.

**268. Ffolliott, P.F.; Brooks, K.N. 1986. Multiple use: Achieving diversified and increased income within a watershed management framework. In: Strategies, approaches and systems in integrated watershed management. FAO Conservation Guide 14, pp. 114–123.**

Different forms of multiple use and the means of evaluating multiple resource alternatives are presented in this paper. Pilot projects of multiple-use planning and implementation, such as the Beaver Creek watershed, are needed in developing countries to demonstrate the viability of this approach to achieve environmentally sound and sustainable resource management.

**269. Ffolliott, P.F.; Brooks, K.N. 1989. The role of multiple use in integrated watershed management watershed management. Journal of Science and Techniques of Soil and Water Conservation in Shanxi Province 1989 2:43–47. (Chinese)**

The multiple use concept and its importance to the development of sustainable and integrated watershed management are described. Multiple-use strategies rather than multiple-use methodologies are stressed.

**270. Ffolliott, P.F.; Thorud, D.B. 1976. Watershed managements' effects on many resources. Arizona Watershed Symposium Proceedings 19:39–42.**

The effect of watershed management practices on natural resources is illustrated through a review of water-yield improvement experiments in mixed conifer forests, ponderosa pine forests, and chaparral shrublands. Water-yield improvement experiments are discussed with particular reference to response functions for water, timber, livestock, wildlife, and soil resources.

**271. Ffolliott, P.F.; Thorud, D.B. 1977. Water resources and multiple use forestry in the Southwest. Journal of Forestry 75(8):469–472.**

Research indicates that modifications of vegetation on upstream watersheds can increase water yields. Other resource values are also obtained and sometimes enhanced by these modifications.

**272. Ffolliott, P. F.; Clary, W.P.; Kruse, W.H. 1978. Effects of grazing on multiple use values of a cleared ponderosa pine watershed. In: Abstract of papers. The 31st Annual Meeting of the Society for Range Management, San Antonio, Texas, February 7–9, 1978, p. 46. (Abstract)**

The impact of 5 years of spring-fall grazing by cattle on a 188-acre watershed is described in terms of multiple-use values. Herbage production was maintained, although composition varied from year-to-year. There was no change in water yield or sediment production that could be attributed to grazing. Deer and elk use declined following cattle introduction.

**273. Fox, K.; Garrett, L.D. 1989. Beaver Creek and Multi resource management forestry. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185. pp. 1–5.**

The emergence of Multi resource forest management in the Southwest is related to the efforts of researchers on the Beaver Creek project and later teaching and research efforts at the NAU School of Forestry. A brief history of the Beaver Creek project, and its contributions to Multi resource management science and practice in the Southwest is presented.

**274. Garrett, L.D. 1986. Understanding Multi resource options on Arizona's national forest system lands. Arizona Water Symposium Proceedings 30:39–47.**

Increasing demand for commodities from and amenities on forest land by the growing Arizona population are hampered by lack of information on the integrated, Multi resource impacts from management practices. Research programs designed to assist managers in developing improved management decisions are discussed.

**275. Pearson, H.A.; Jameson, D.A. 1967. Relationship between timber and cattle production on ponderosa pine range: The Wild Bill Range. USDA Forest Service, Fort Collins, Colorado.**

A relationship between herbage production and ponderosa pine overstory density is graphically illustrated for a study area in north central Arizona.

**276. Pollisco, R.R.A. 1987. Management of pinyon-juniper woodlands for the sustained yield of wood and water. MS Thesis, University of Arizona, Tucson, Arizona.**

An updated inventory of woodlands on the Beaver Creek watershed is presented. Use of the inventory information in management decision making is discussed.

**277. Smith, J.H.G. 1980. The conference tours: A synthesis of observations on multiple-use research and application in northern Arizona. In: IUFRO/MAB Conference: Research on multiple use of forest resources. USDA Forest Service, General Technical Report WO-25. pp. 155–158.**

Multiple-use research on the Beaver Creek Biosphere Reserve was reviewed as part of a field tour.

**278. Tecle, A.; Covington, W.W. Technical editors. 1991. Multi resource management of southwestern ponderosa pine forests: The status of knowledge. USDA Forest Service, Southwestern Region Report.**

This report is a synthesis of research-based knowledge concerning Multi resource management conditions in Southwestern pine forests. The current status and trends of individual resource conditions, and their interactions under natural and various vegetation management regimes was explored and reviewed in a Multi resource management context. Major topics include forest overstory/understory relationships, tree growth and yield, forest hydrology and watershed management, forest water quality, recreation and esthetics, and forest wildlife management. The contributions from the Beaver Creek project, and their significance are apparent.

**279. Tecle, A.; Covington, W.W.; Hamre, R.H. Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185.**

This conference brought resource managers and specialists, academicians, agency researchers, and the public together to focus on improving integrated ecosystem management of forest land. The link between Multi resource forest management in the Southwest and on the Beaver Creek project is made.

**280. Tecle, A.; Covington, W.W.; McTague, J.P.; Richards, M.T.; Patton, D.R. 1991. Field guide for Multi resource management of southwestern ponderosa pine forests. USDA Forest Service, Southwestern Region Report.**

This guide provides field personnel with an overview and a brief description of the scientific, technical, and quantitative aspect of published material on Southwestern pine forests. Resource response functions and techniques for estimating biophysical trends in forest systems are summarized.

## Outdoor Recreation and Visual Resources

**281. Anderson, L.M. 1978. Social influences on public perception of the scenic quality of forested landscapes. PhD Dissertation, University of Arizona, Tucson, Arizona.**

Two experiments to ascertain the effects of social variables on public perception of scenic beauty of ponderosa pine settings are described. One experiment concerned the effects of land-use designations on evaluations of forest scenes. The other experiment extended a previous investigation of the effects of information concerning forest ecology on scenic quality perception.

**282. Arthur, L.M. 1975. Testing the predictive utility of scenic beauty description models. PhD Dissertation, University of Arizona, Tucson, Arizona.**

A mathematical test of the utility of forest planning of 3 landscape description techniques: 1) physical feature scaling, 2) design inventory, and 3) timber cruise inventory is presented. Utility is defined as effectiveness in explaining people's preferences for forested landscapes and as strength of relationships of description variables to forest planning variables.

**283. Arthur, L.M. 1977. Predicting scenic beauty of forest environments: Some empirical tests. Forest Science 23(2):151–160.**

Three landscape description techniques, scaling of physical features, inventories of visual features, and timber cruises, were compared for predicting scenic beauty. The timber cruise model seemed to provide the most effi-

cient and effective tool for predicting public preferences and managing forests for increased esthetics benefits.

**284. Arthur, L.M.; Boster, R.S. 1976. Measuring scenic beauty: A selected annotated bibliography. USDA Forest Service, General Technical Report RM-25.**

Of the 167 papers covered on the topic, 95% date from 1965. Citations are divided into 4 categories: 1) literature reviews, 2) inventory methods, 3) public involvement, and 4) miscellaneous. Many annotations also carry a critical comment.

**285. Arthur, L.M.; Daniel, T.C.; Boster, R.S. 1977. Scenic assessment: An overview. Landscape Planning 4:109–129.**

Literature is grouped into 3 categories: 1) descriptive inventories, 2) public evaluations, and 3) economic analyses. Both quantitative and nonquantitative methods within each category are discussed, strengths and weaknesses of the general approaches noted, and occasionally, alternatives suggested.

**286. Boster, R.S. 1973. On the criteria for and possibility of quantifying the esthetics aspects of water resource projects. In: P.J. Brown (ed.), Toward a technique for quantifying aesthetic quality of water resources, PRWG-120-2, Utah State University, Logan, Utah, pp. 6–12.**

This report introduces the colloquium problem of quantifying the aesthetic aspects of water resource projects. and it discusses criteria to judge solutions to the problem, related research efforts, and the "straw man" as a possible solution framework.

**287. Boster, R.S. 1976. Methodologies for scenic assessment. In: Harper, D. and J. Warbach (eds.), Proceedings of a Conference/Workshop: Visual Quality and the Coastal Zone, College of Environmental Science and Forestry, State University of New York, Syracuse, New York, pp. 78–102.**

The first part of this paper reviews literature on the various methodologies available for describing and predicting scenic beauty. The second part describes the esthetics research program being conducted in the Southwest.

**288. Boster, R.S.; Daniel, T.C. 1972. Measuring public responses to vegetative management. Arizona Watershed Symposium Proceedings 16:38–43.**

Esthetic judgments of random color slides, taken in areas of ponderosa pine forest subjected to an array of vegetative manipulations from clearcut to essentially natural, were evaluated in terms of the psychologists' theory of signal detection. Results appear to be valid, reliable, and useful.

**289. Brown, T.C.; Daniel, T.C. 1984. Modeling forest scenic beauty: Concepts and application to ponderosa pine. USDA Forest Service, Research Paper RM-256.**

Statistical models are presented that relate near-view scenic beauty of pine stands in the Southwest to variables describing physical characteristics. The models suggest that herbage and large ponderosa pine contribute to scenic beauty, while numbers of small and intermediate-sized pine trees and downed wood, especially slash, detract from scenic beauty.

**290. Brown, T.C.; Daniel, T.C. 1986. Predicting scenic beauty of timber stands. Forest Science 32:471–487.**

The psychophysical approach to developing scenic beauty models is extended to the timber-stand level. The models agree with earlier studies that focused on 1-acre plots, suggesting that herbage and large pine increase scenic beauty, while downed wood and tree grouping decrease scenic beauty.

**291. Brown, T.C.; Daniel, T.C. 1987. Context effects in perceived environmental quality assessment: scene selection and landscape quality ratings. Journal of Environmental Psychology 7:233–250.**

Observer groups rated the scenic beauty of forest scenes represented by color slides presented in the context of different scene mixtures. Effects of different scene contexts on scenic beauty judgments are described. The assessment context should be made to match the "real world" context in which the results are applied.

**292. Daniel, T.C. 1976. Criteria for the development of perceived environmental quality indices. In: Craik, K.H. and E.H. Zube editors, Perceived environmental quality: Research and Applications. Plenum Press, New York, pp. 27–45.**

Essential or desirable determinants of environmental quality are listed. Considerations for the measurement of perceived environmental quality of the environment, or its components, are discussed. The indices obtained can provide a current appraisal of the environment and can help to gauge the impacts that management actions have on the perceived environmental quality.

**293. Daniel, T.C. 1977a. Public perception based assessment of esthetics resources: The scenic beauty estimation method. In: Proceedings, Environmental Psychology: Arid, Forest and Urban Regions, reprint of papers read at Amer. Assoc. for Advance. of Sci., Denver, CO. Department of Psychology, University of Arizona, Tucson.**

The Scenic Beauty Estimation (SBE) method quantitatively measures esthetic preferences for wildlands. Extensive testing with user, interest, and professional groups validated the method. SBE is an efficient and objective means for assessing the scenic beauty of public forests and wildlands and for predicting esthetic consequences of alternative land uses.

**294. Daniel, T.C. 1977b. Measuring public preference for scenic quality. In: Thames, J.L. (ed.), Disturbed land reclamation and use in the Southwest. University of Arizona Press, Tucson, pp. 189–202.**

The Scenic Beauty Estimation (SBE) method evaluates the scenic impacts of mining and other land-use activities on Southwestern landscapes and assesses the effectiveness of subsequent reclamation efforts.

**295. Daniel, T.C. 1977c. Public perception based assessment of forest aesthetics. In: Proceedings of the 1977 National Convention, Society of American Foresters, Oct. 1977, pp. 323–327.**

Measurement of the aesthetic quality of forest landscapes with the Scenic Beauty Estimation (SBE) method is described. Applications of the SBE method in north central Arizona are presented.

**296. Daniel, T.C. 1979. Integration of esthetics evaluation with visual inventory and physical feature models. Final Report Prepared by the University of Arizona, Tucson, Arizona, Submitted to the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Although public response to vegetative treatments is variable, the Scenic Beauty Estimation method is an efficient and objective means for assessing the scenic beauty of forests and other wildlands. This methodology can also be used to predict the esthetic consequences of alternative land-management practices.

**297. Daniel, T.C.; Anderson, L.M.; Schroeder, H.W.; Wheeler, L., III. 1977. Mapping the scenic beauty of forest landscapes. Leisure Science 1:35–52.**

Observers rate the scenic beauty of sites using randomly oriented color slides. Ratings are transformed to scenic beauty estimates, which is a standardized relative index. A computer program produces interpolated maps. An application in a ponderosa pine forest in Arizona is presented.

**298. Daniel, T.C.; Boster, R.S. 1976. Measuring landscape esthetics: The scenic beauty estimation method. USDA Forest Service, Research Paper RM-167.**

The Scenic Beauty Estimation (SBE) method quantitatively measures esthetic preferences for wildlands. Extensive testing with user, interest, and professional groups validated the method. SBE shows promise as an efficient and objective means for assessing scenic beauty of public forests and wildlands and for predicting esthetic consequences of alternative land uses.

**299. Daniel, T.C.; Wheeler, L.; Boster, R.S.; Best, P.R., Jr. 1973. Quantitative evaluation of landscapes: An application of signal detection analysis to forest management alternatives. Management-Environment Systems 3:330–344.**

Six ponderosa pine forest areas, each representing a different vegetative treatment, were presented to individuals in a series of color slides for detection and esthetic judgment of treatments. Signal detection analyses gave systematic and reliable indices of observers' reactions to different forest landscapes.

**300. Richards, M. T. 1974. An activity topology for outdoor recreation in the Mogollon Rim area. MS Thesis, University of Arizona, Tucson, Arizona.**

This report describes a technique for aggregating conceptually linked activities and relating them to recreation visitor characteristics to permit quantification of activity preferences. Patterns of visitors' activity preferences and the factors that constrain these preferences are described.

**301. Richards, M.T.; Daniel, T.C. 1989. Recreation and esthetics management in southwestern ponderosa pine: Assessing research needs. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185. pp. 196–207.**

Explicit relationships need to be specified between management activities for the production of commodities and the provision of recreation and esthetics opportunities in Southwestern ponderosa pine forests. Models for recreation experience opportunities and forest scenic beauty are reviewed and a combined "expert judgement" model is proposed. The research needs for such a model are assessed.

**302. Richards, M.T.; Daniel, T.C. 1991. Chapter 7. Management of recreation and esthetic values in southwestern ponderosa pine forest. In: Tecle, A. and W.W. Covington, Technical editors. 1991. Multi resource management of southwestern ponderosa pine forests: The status of knowledge. USDA Forest Service, Southwestern Region Report, pp. 315–360.**

Descriptions and definitions of forest recreation experiences, the relationship of recreation opportunities to common forest management activities, and a proposal of an approach to modeling relationships between recreational and other uses of forestlands are presented. Consideration is given to the esthetic quality of forests, both in its own right and as an important contributor to many forest recreation activities.

**303. Richards, M.T.; King, D.A. 1977. Six recreation demand source populations in Arizona. USDC National Technical Information Service, PB-268–129.**

Results of a general population survey of potential outdoor recreationists from 6 demand source populations in Arizona are presented. Respondent's social and economic characteristics are presented and the structure of their recreational activity participation at 5 national forest areas is provided. These data were collected as an information base for land managers, researchers, and others interested in the economic demand and consumption of natural resources for recreational purposes.

**304. Richards, M.T.; King, D.A.; Kurtz, W.B. 1977. Recreational visitors to the Mogollon Rim area of Arizona. USDC National Technical Information Service, PB-268–128.**

This report describes the social and economic characteristics of recreational visitors to the Mogollon Rim area of Arizona. The reports provides an information base for planners, managers, and researches regarding outdoor recreational use of national forest land in the area. A description of recreational activity participation is also given for area visitors, and a synthesis of their options regarding their outdoor experiences is provided.

**305. Schroeder, H.W. 1977a. Predicting aesthetic evaluations for forest roads. MS Thesis, University of Arizona, Tucson, Arizona.**

Scenic beauty is used as a variable in overlay mapping techniques that combine different variables into a single composite surface to be used for selecting desirable forest road corridors. Results suggest that information about scenic beauty at locations may be used to select road corridors through an area.

**306. Schroeder, H.W. 1977b. Predicting the aesthetic quality of forest roads. In: Proceedings, Environmental Psychology: Arid, Forest and Urban Regions. Reprint of papers read at Amer. Assoc. for Advance. of Sci., Den-**

**ver, CO. Department of Psychology, University of Arizona, Tucson, Arizona.**

Scenic beauty is used as a variable in overlay mapping techniques that combine different variables into a single composite surface to be used for selecting desirable forest road corridors. Results suggest that information about scenic beauty at locations may be used to select road corridors through an area.

**307. Simpson, C.J.; Rosenthal, T.L.; Daniel, T.C.; White, G.M. 1976. Social influence variations in evaluating managed and unmanaged forest areas. Journal of Applied Psychology 61:759–765.**

The effects of using a model's ratings, or the reported norms of others as social anchoring devices, are compared with having subjects read a persuasive message as a means to enhance public toleration of managed practices in ponderosa pine forests. Social-influence implications for pragmatic forest-use policy and theory are discussed.

**308. Sublette, W.J.; Martin, W.E. 1975. Outdoor recreation in the Salt-Verde Basin of central Arizona: Demand and values. University of Arizona Experiment Station, Technical Bulletin 218.**

Higher net values and larger expenditures are associated with sites that have water- based recreation, considerable development, and easy access.

**309. Thompson, A.E. 1972. Research in landscape architecture. Progressive Agriculture in Arizona 24:8–11, 16.**

A discussion of the current program and research efforts in landscape architecture at the University of Arizona is presented.

## Planning

**310. Burford, C.L.; Mertes, J.D.; Jones, T.W. 1976. Technological and environmental planning consideration to minimize the environmental impact of transporting people and products through wildland areas: An overview. Department of Industrial Engineering and Park Administration, Landscape Architecture and Horticulture, Texas Technical University, Lubbock, Texas.**

This paper identifies, investigates, and evaluates the economic, environmental, and social implications of technically feasible mass conveyance systems that could be used to solve specific visitor conveyance problems at recreational developments in forest wildland areas.

**311. Burford, C.L.; Page, L.E.; Mertes, J.D. 1978. Development, trial application and evaluation of a transportation mode alternative analysis and specification selection procedure for use in wildland transportation planning. Texas Technical University, Lubbock, Texas, Final Report.**

This report identifies, investigates, and evaluates the economic, environmental, and social implications of technically feasible mass conveyance systems that could be used to solve specific visitor conveyance problems at recreational developments in forest wildland areas.

**312. Covington, W.W.; Wood, D.B.; Tecle, A.; Fox, B.E. 1989. Current status of the TEAMS decision support system in forest plans. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185, pp. 221–227.**

Terrestrial Ecosystem Analysis and Modeling System (TEAMS) is a computer-based decision-support system that helps when developing site-specific treatment alternatives. TEAMS combines a geographical information system, a Multi resource simulation model, an optimization module, and a graphics output display package, which are organized around a relational database management system.

**313. Ffolliott, P.F. 1995. Computer simulation techniques for planning and analysis of natural resource management. In: Wang, L., and K. N. Brooks, eds. 1995. Soil and water conservation and environmental protection on the upper and middle reaches of the Changjiang River Basin. Chinese Forestry Press, Beijing, China, pp. 161–168. (Chinese)**

Applications of computer multiple-resource simulation techniques used in planning for environmentally sound and economically viable natural resource management are described. Data sets representing the conditions on the Beaver Creek watershed provided the required inputs in sample exercises.

**314. Fox, B.E.; Wood, D.B.; Covington, W.W.; Tecle, A. 1989. The effect of planning unit size on implementing forest plans. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185, pp. 237–246.**

The pattern and magnitude of resource flows over time and the direct and opportunity costs associated with implementing forest plans may depend on the size of the planning units. A preliminary examination of this Multi resource analyses using a computer-aided decision-support system was performed on different sized planning units within the same ponderosa pine dominated watershed in north central Arizona. Results of these analyses are reported, with preliminary assessment of the efficiencies, opportunity costs, and tradeoffs.

**315. Johnson, C.M. 1980. Computer techniques for land management planning. USDA Forest Service Research Note RM-387.**

A system for storage and retrieval of about 200 land-management planning techniques for the Rocky Mountain and Southwestern Regions of the Forest Service is described. An abstract of each technique can be retrieved from remote terminals via telephone.

**316. Eagan, D.E.; Larson, F.R. 1972. Proposed principles and standards for planning water and related land resources. In: Dynamics of Forest Policy Symposium, Colorado State University, Fort Collins, CO. pp. 70–78.**

A discussion of the principles and standards that were published in the Federal Register, and their implications for management planning on public land is presented.

**317. Levi, D. 1977. Managing resources in a simulated commons situation: The effects of goal conditions, orientation and experience. MS Thesis, University of Arizona, Tucson, Arizona.**

A simulated cattle ranch is used to examine the "common" situation. Three variables were examined: goal conditions, orientation, and experience. The results demonstrate some of the problems encountered when generalizing from a simulated common situation to real world common situations and suggests ways that simulated common situations could be improved.

**318. McKee, M. 1979. Index utilization in natural resources planning: A review and evaluation of techniques. In: Proceedings of a workshop on Index Construction for Use in High Mountain Watershed Management, Utah Water Research Laboratory, Utah State University, UWRL/C-79/01, Logan.**

Evaluation of natural resource planning techniques is presented. Evaluations were based on technique suitability to a particular situation.

**319. McKee, M.; Simmons, R. 1979. A preliminary test and demonstration of the indifference-scaled factor profile technique in Forest Service regional planning. Utah State University Final Report, Logan, Utah. Prepared for USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.**

Applicability of the technique is determined with the framework of regional planning requirements.

**320. Rasmussen, W. O.; Ffolliott, P.F.; Verma, T.R.; Thames, J.L. 1980. Environmental analysis for land use planning in the arid zones. In: Mann, H.S., ed. Arid zone research and development. Scientific Publishers, Jodhpur, India, pp. 69–73.**

An environmental analysis approach, using ecosystem simulation models as a component, is presented as a means for effective land-use planning. Physical, biological, and climatic parameters are analyzed to determine the potential productivity levels of an area. Agriculture, livestock grazing, mining, and urban development are assessed as land-use practices.

**321. Rasumssen, W.O., Weisz, R.N.; Ffolliott, P.F.; Carder, D.R. 1980. Planning for forest roads: A computer-assisted procedure for selection of alternative corridors. Journal of Environmental Management 11:93–104.**

A methodology for incorporating economic and esthetics criteria within a forest road corridor selection process is presented.

**322. Suhr, J.; Carder, D.R. 1979. A comparison of three index techniques in use in Forest Service planning. In: Proceedings of a Workshop on Index Construction for Use in High Mountain Watershed Management, Utah Water Research Lab., Utah State University, UWRL/G-79/01, Logan.**

Planning techniques are evaluated in terms of data requirements, availability of data, and sequence of planned activities.

**323. Weisz, R.N.; Carder, D.R. 1975a. Development of land use planning and transportation planning systems for National Forest Management: A status overview. In: Meadows, J., B. Bare, K. Ware, C. Row, eds. Systems Analysis and Forest Resource Management, Society of American Foresters, Bethesda, MD. pp. 87–104.**

This report describes how emerging computer-aided planning support systems can be made operational. Existing systems, linkages, and interfaces between systems and the USDA Forest Service planning and decision-making process are examined.

**324. Weisz, R.N.; Carder, D.R. 1975b. Development of land use planning and transportation planning systems for National Forests. In: Man, leisure, and wildlands: A complex interaction. Proceedings of First Eisenhower Consortium Research Symposium, Bulletin 1:143–156.**

This report describes how emerging computer-aided planning support systems can be made operational. Existing systems, linkages, and interfaces between systems and the USDA Forest Service planning and decision-making process are examined.

**325. Wood, D.B.; Covington, W.W.; Tecle, A.; Fox, B.E.; Gordon, C. 1989. Use of a computer-aided decision support system in forest plan implementation. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multi resource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185. pp. 228–236.**

Terrestrial Ecosystem Analysis and Modeling System (TEAMS) is a decision support system used to develop stand-specific prescriptions for a 20,000 acre forest management area on the Navajo Reservation. A comparison of TEAMS results with those developed by conventional methods indicated that TEAMS has great potential for improving forest management decisions.

## Policy

**326. Clary, W. P. 1981. Grazing, natural resource policy, and biosphere reserves. In: Ffolliott, P.F., and G. Halffter, technical coordinators. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88, pp. 21–23.**

The concept of biosphere reserves involves a broader conservation philosophy than contained in earlier policies for livestock grazing in the Western United States. Biosphere reserves provide land managers and others with a better understanding of the long-term dangers of improper grazing management.

**327. Cortner, H.J.; Berry, M.P. 1977. The Arizona Water Resources Committee: An historical perspective. Arizona Watershed Symposium Proceedings 21:5–15**

An examination of the Arizona Water Resources Committee is presented. This committee was formed in 1956 to develop ways increase water yields from Arizona watersheds. Changes in committee membership, organizational resources, program objectives, and relations with other private groups and public agencies are discussed.

**328. Ffolliott, P.F. 1981. Integration of wildlife and other natural resources policies. In: Ffolliott, P.F., and G. Halffter, technical coordinators. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88, pp. 24–25.**

This paper outlines the fundamental considerations upon which wildlife resource management should be based. Impacts of wildlife policies on other natural resources, and impacts of other natural resources policies on wildlife are discussed.

**329. Ffolliott, P.F. 1983. Implications of snag policies on management of southwestern ponderosa pine forests. In: Davis, J.W., G.A. Goodwin, and R.A. Ockenfels, technical coordinators. Snag habitat management: Proceedings of the symposium. USDA Forest Service, General Technical Report RM-99, pp. 28–32.**

This report discusses whether the snag retention policies of the USDA Forest Service could be met solely through natural mortality, and whether timber would be lost and revenues foregone if snags are artificially created.

**330. Ffolliott, P.F.; Halffter, G. technical coordinators. 1981. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88.**

The objective of the papers presented in this seminar was to promote cooperation among natural resources policy makers, scientists, and educators within the framework of the international Man and the Biosphere program. Included are 20 invited and volunteer papers, and a summary of visits to La Michilia and Mapimi Biosphere Reserves.

**331. Halffter, G. 1981. Biosphere reserves: A new method of natural protection. In: Ffolliott, P.F., and G. Halffter, technical coordinators. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88, pp. 3–6.**

The role of the biosphere reserves, created by the Institute of Ecology in Mexico, concerning rational use policies and natural resource protection are presented. Development of these reserves requires international cooperation and collaboration of the public in conjunction with high-quality research and education.

**332. Nowakowski, N.A. 1980. Assessment of snag policies and their effects on timber harvests. MS Thesis, University of Arizona, Tucson, Arizona.**

In forest stands where natural mortality does not provide enough snags to meet policy requirements, artificial snag creation is necessary. In this report, a methodology is developed to illustrate timber volumes lost and associated revenues foregone under various snag retention options.

**333. Stairs, G.R. 1981a. Evaluation of natural resources policy alternatives. In: Ffolliott, P.F., and G. Halffter, technical coordinators. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88, pp. 37–40.**

Evaluating natural resources policy by developing accurate data bases and quantitatively evaluating the data through systems and simulation models are necessary preludes to policy formulation. At the interface between quantification and integrated socioeconomic decisions, major opportunities are available to define policy alternatives for presentation to the public and elected officials.

**334. Stairs, G.R. 1981b. Impacts of policies on specific natural resources: Forest resources. In: Ffolliott, P.F., and G. Halffter, technical coordinators. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88, pp. 7–9.**

A hierarchy of policy needs is identified in this paper including: recognizing the importance of conservation and restoration of forest resources, selecting a policy to provide the goods and services desired, and considering domestic consumption and local use or export and industrial production.

**335. Stairs, G.R. 1981c. Social and environmental consequences of natural resources policies. In: Ffolliott, P.F., and G. Halffter, technical coordinators. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88, pp. 1–2.**

The primary concerns facing policy decision makers are discussed in this report. These concerns include the completeness of a matrix of broad issues and a need to bring contemporary technical and scientific competency to bear upon more specific issues. A time table for action is outlined.

## Range Management

**336. Bojorquez-Tapia, L.A.; Ffolliott, P.F.; Guertin, D.P. 1990. Herbage production-forest overstory relationships in two ponderosa pine forests. Journal of Range Management 43:25–28.**

A set of regression equations were developed and statistically analyzed in terms of coefficients of determination and standard errors of estimate. Hyperbolic, logarithmic, and exponential transformations met the specified acceptance criteria.

**337. Clary, W.P. 1964. A method for predicting potential herbage yield on the Beaver Creek Pilot Watershed. In: Forage Plant Physiology and Soil-Range Relationships, American Society of Agronomy Special Publication No. 5. pp. 244– 250.**

Results are presented to determine which soils and topographic variables are most influential and are therefore useful in predicting herbage production potential on the watershed. Surface soil texture and position on the slope were useful predictors of herbage production on cleared, wooded sites.

**338. Clary, W.P. 1970. The relationship of herbage production on Springerville soils to Utah juniper overstory and precipitation. American Society of Range Management, Abstract of Papers 23:69.**

Herbage and perennial grass yields associated with intact Utah juniper overstory and overstory removed by cabling are described for a study area in north central Arizona.

**339. Clary, W.P. 1971. Effects of Utah juniper removal on herbage yields from Springerville soils. Journal of Range Management 24:373–378.**

Yields of understory vegetation increased from 223 lb./acre, including 50 lb. of perennial grasses, to 981 lb., including 193 lb. of perennial grasses, after overstory removal in northern Arizona. Successional trends did not follow a smooth sequence; many areas remained in an annual forb-half shrub stage for several years.

**340. Clary, W.P. 1972. Phenology, production, and water use of ecotypes of *Sitanion hystrix* (Nutt.) J. G. Smith. PhD Dissertation, Colorado State University, Fort Collins, Colorado.**

This report discusses ecotypic differentiation in *Stanion hystrix* grass as a response to climatic conditions. Plant collections were obtained from 7 states and observations and measurements were made on plant materials grown under uniform conditions in a transplant garden and in a growth chamber.

**341. Clary, W.P. 1974. Response of herbaceous vegetation to felling of alligator juniper. Journal of Range Management 27:387–389.**

Felling 13% of the alligator juniper cover in north central Arizona increased total herbage production 38% and forage plant production 45%. These increases were highly variable. There was little or no apparent response in 3 of 7 postfelling years.

**342. Clary, W.P. 1975a. Range management and its ecological basis in the ponderosa pine type of Arizona: The status-of-our-knowledge. USDA Forest Service, Research Paper RM-158.**

This report summarizes and evaluates the available information about pine-bunchgrass ranges including physical-biological characteristics, factors influencing livestock production, grazing allotment conditions, and economics. The correlation between grazing with other uses is also discussed. Several knowledge gaps are identified.

**343. Clary, W.P. 1975b. Ecotypic adaptation in *Sitanion hystrix*. Ecology 56:1407–1415.**

The plant population studied adapted to different climatic conditions primarily through variations in timing of phenological development and rate of growth. There were no differences in water use efficiency. The primary factors that influence morphological and production characteristics may be more numerous or complex than those that influence phenology.

**344. Clary, W.P. 1978a. Arizona fescue mountain rangelands. Abstract of Papers, 1st International Rangeland Congress, Denver, Colorado, p. 22.**

Characteristics of Arizona fescue mountain rangelands are described including herbage productions rates, protein availability, and beef production potential.

**345. Clary, W.P. 1978b. Arizona fescue mountain rangelands. In: Hyder, D.N., editor. Proceedings of the first international rangeland congress, Denver, Colorado, August 14–18, Society of Range Management, p. 205–207.**

Arizona fescue rangelands occur in the mountains of Arizona, Colorado, and New Mexico. Brief descriptions of their botanical, climatic, and edaphic characteristics are given followed by discussions of successful patterns, forage nutritional values, understory-overstory relationships, plant and animal biomass, and human uses.

**346. Clary, W.P. 1979. Variation in leaf anatomy and $CO_2$ assimilation in *Sitanion hystrix* ecotypes. Great Basin Naturalist 39:427–432.**

Collections of *Sitanion hystrix*, known to differ in phenological development, height, dry matter production, and total water use, were examined for possible differences in leaf anatomy and $CO_2$ assimilation rates. Collections originating in warm, dry habitats produced the narrowest leaves with the fewest veins. $CO_2$ assimilation rates were similar on per-unit weight basic, therefore, total assimilation varied as a function of plant size.

**347. Clary, W.P.; Ffolliott, P.F. 1966. Differences in herbage-timber relationships between thinned and unthinned ponderosa pine stands. USDA Forest Service, Research Note RM-74.**

Herbage production under thinned and unthinned ponderosa pine stands are compared by logarithmic equations for a study area in north central Arizona.

**348. Clary, W.P.; Ffolliott, P.F. 1972. A selected and annotated bibliography of understory-overstory relationships. Arizona Agricultural Experiment Station, Technical Bulletin 198.**

A summary of selected literature on understory-overstory relationships published through 1971 is provided. The bibliography is organized relative to coniferous, deciduous, mixed coniferous-deciduous, and shrub overstories.

**349. Clary, W.P.; Ffolliott, P.F.; Jameson, D.A. 1968a. Relationship of different forest floor layers to herbage production. USDA Forest Service, Research Note RM-123.**

Herbage production decreases as individual layers and total depth of forest floor increases. The H layer (total depth of the forest floor) accounts for more variation in herbage production than the L or F layers. Management practices that remove only the L and F layers cannot appreciably increase herbage production.

**350. Clary, W.P.; Ffolliott, P.F.; Jameson, D.A. 1968b. Some characteristics of the forest floor under ponderosa pine in Arizona. USDA Forest Service, Research Note RM-127.**

In north central Arizona, logarithmic equations describe relationships between herbage production and individual layers and total depth of ponderosa pine forest floor.

**351. Clary, W.P.; Ffolliott, P.F.; Larson, F.R. 1978. Factors affecting forage consumption by cattle in Arizona ponderosa pine forests. Journal of Range Management 31:9–10.**

Forage consumption was significantly correlated with

forage production and tree density but not with steepness of slope, rockiness of soil, or distance from water. This suggests that good range management practices can effectively distribute livestock use.

**352. Clary, W.P.; Ffolliott, P.F.; Zander, A.D. 1966. Grouping sites by soil management areas and topography. USDA Forest Service, Research Note RM-60.**

Relationships between herbage production and ponderosa pine overstory density for different productivity strata are graphically illustrated for a study area in north central Arizona.

**353. Clary, W.P.; Grelen, H.E. 1978a. A comparison of beef gain potentials on cool semiarid and subtropical pine forest ranges. Abstracts of Papers. 1st International Rangeland Congress, Denver, Colorado, p. 55.**

Similarities and differences in ponderosa pine ranges in central Arizona and in longleaf-slash pine ranges in central Louisiana are presented including a comparison of beef gain potentials.

**354. Clary, W.P.; Grelen, H.E. 1978b. A comparison of beef gain potentials on cool semiarid and subtropical pine forest ranges. In: Hyder, D.N., editor. Proceedings of the first international rangeland congress, Denver, Colorado, August 14–18, Society of Range Management, pp. 600–602.**

Despite the climatic and ecological differences between cool semiarid and subtropical pine forested ranges, available data suggest that their potentials for beef production are similar. Better forage quality in the semiarid region tends to compensate for more forage in the subtropical region. Longleaf-slash pine forest ranges have greater potential for the production of beef in combination with timber than ponderosa pine ranges.

**355. Clary, W.P.; Jameson, D.A. 1980. Understory response after tree removal, herbicide application, and protection from grazing in Arizona pinyon-juniper. Abstracts of Papers. 33rd Annual Meeting, Society for Range Management, San Diego, California, p. 39.**

Herbage production following overstory removal from different pinyon-juniper sites was evaluated. Average annual production increased from 216 to 1,440 kg/ha. Prediction equations that accounted for up to three-fourths of the variation in posttreatment production were determined.

**356. Clary, W.P.; Jameson, D.A. 1981. Herbage production following tree and shrub removal in the pinyon-juniper type of Arizona. Journal of Range Management 34:109–113.**

Grasses increased in composition from 46 to 73%, while forbs decreased from 21 to 19%, and half-shrubs and shrubs decreased from 33 to 8%.

**357. Clary, W.P.; Kruse, W.W. 1979. Phenology and rate of height growth of some forbs in the Southwest ponderosa pine type. USDA Forest Service, Research Note RM-376.**

In a 3-year study, 2 of 6 primary forb species had possible value as range readiness indicators. Species varied between seasons and sites as available sources of deer forage. Twenty-four secondary forb species showed a diversity of palatable green forage becoming available throughout the growing season.

**358. Clary, W.P.; Morrison, D.C. 1973. Large alligator junipers benefit early-spring forage. Journal of Range Management 26:70–71.**

Production of early-spring grasses in central Arizona was 4 to 5 times higher under crowns of large alligator junipers than away from trees. Because all green forage grazed by animals at this time of year grew under these trees, they should be protected during control operations.

**359. Clary, W.P.; Pearson, H.A. 1969. Cattle preferences for forage species in northern Arizona. Journal of Range Management 22:114–116.**

Preference ratings, by comparisons with bottlebush squirreltail, showed Kentucky bluegrass, Arizona fescue, and mountain muhly were preferred in ponderosa pine in summer, while prairie junegrass was preferred in spring-fall in the pinyon-juniper type.

**360. Clary, W.P.; Pearson, H.A. 1976. Herbage changes following thinning and grazing of a southwestern ponderosa pine stand. Society of Range Management 29:37. (Abstract)**

After pine stands are thinned, herbage yields usually increase rapidly to levels considerably higher than those under unthinned stands of similar basal area, then they slowly decline. Grazing accelerates the decline. Plant composition, seeded versus native, is not necessarily an important factor.

**361. Covington, W.W.; Fox, B.E. 1991. Chapter 4. Overstory:understory relationships in southwestern ponderosa pine. In: Tecle, A. and W.W. Covington, Technical editors. 1991. Multi resource management of southwestern ponderosa pine forests: The status of knowledge. USDA Forest Service, Southwestern Region Report. pp. 121–161.**

The standing crop, species composition, and productivity of understory plants influence a wide array of pine forest ecosystem characteristics important to Multi resource management. Historically pine understory has been examined primarily as a source of forage for livestock and as a source of composition that can retard regeneration of pine trees. Emphasis on management of pine forests for Multi resource benefits has lead to increasing focus on the importance of understory characteristics in influencing esthetics, erosion and water quality, and wildlife habitat.

**362. Ffolliott, P.F. 1983. Overstory-understory relationships: Southwestern ponderosa pine. In: Bartlett, E. T., and D. R. Betters, eds. Overstory-understory relationships in western forests. Western Regional Research Publication 1:13–18.**

Empirical equations relating understory composition and production to overstory density and other characteristics on the Beaver Creek Biosphere Reserve and elsewhere are presented. Alternative mathematical models were used.

**363. Ffolliott, P.F.; Clary, W.P. 1972. A selected and annotated bibliography of understory-overstory vegetation relationships. Arizona Agricultural Experiment Station Technical Bulletin 198, 33 p.**

Selected literature on understory-overstory relationships published through 1971 are summarized.

**364. Ffolliott, P.F.; Clary, W.P. 1974. Predicting herbage production from forest growth in Arizona ponderosa pine. Progressive Agriculture in Arizona 26:3–5.**

Annual herbage production decreased as annual forest growth increased, in an unexpected linear relationship. Herbage prediction was improved by developing families of curves that added precipitation and elevation strata to timber growth.

**365. Ffolliott, P.F.; Clary, W.P. 1975. Differences in herbage-timber relationships on sedimentary and igneous soils in Arizona ponderosa pine stands. Progressive Agriculture in Arizona, 27:6–7.**

Significant differences in herbage-timber relationships on sedimentary and igneous soils indicated that herbage production predictions that do not account for soil differences may not be sufficiently accurate for use in land-use planning or stratification.

**366. Ffolliott, P.F.; Clary, W.P. 1982. Understory-overstory vegetation relationships: An annotated bibliography. USDA Forest Service, General Technical Report INT-136.**

A working tool for natural resources specialists and land-use planners describing understory production, density, or composition with specified overstories, or changes in understory characteristics resulting from conversion or modification of the overstories is provided.

**367. Gallina, S.; Ffolliott, P.F. 1993. Overstory-understory relationships: Oak-pine forests of Sierra Madre Occidentalis, Mexico. In: Bartlett, E.T., and D.R. Betters, editors. Overstory-understory relationships in western forests. Western Regional Research Publication 1:13–20.**

Empirical equations relating understory composition and production to overstory density and other characteristics on the La Michilia Biosphere Reserve are presented. Alternative mathematical models were used.

**368. Jameson, D.A. 1965. Phenology of grasses of the northern Arizona pinyon- juniper type. USDA Forest Service, Research Note RM-47.**

Phenology of several cool- and warm-season forage plants in the pinyon-juniper type in north central Arizona are presented. With a good mixture of grasses, this pinyon-juniper range should supply ample green forage from April 1 to September 30, and some green feed all winter.

**369. Jameson, D.A. 1966a. Competition in a blue grama broom snakeweed actinea community and responses to selective herbicides. Journal of Range Management 19:121–124.**

A table of correlation coefficients is provided to illustrate the association among plant yields, including perennial grasses, broom snakeweed, and Cooper actinea, on a study area in north central Arizona.

**370. Jameson, D.A. 1966b. Pinyon-juniper litter reduces growth of blue grama. Journal of Range Management 19:214–217.**

Pinyon and juniper litter is reported as the major overstory factor associated with the reduction of blue grama on a study area in north central Arizona.

**371. Jameson, D.A. 1967. The relationship of tree overstory and herbaceous understory vegetation. Journal of Range Management 20:247–249.**

The use of a 5-parameter transition sigmoid growth curve to express the relationship between herbaceous understory and tree overstory is described and illustrated with data from north central Arizona. Overstories considered are pinyon, juniper, and ponderosa pine.

**372. Jameson, D.A. 1970. Juniper root competition reduces basal area of blue grama. Journal of Range Management 23:217–218.**

A table of blue grama basal area with and without oneseed juniper root competition is presented for a study area in north central Arizona.

**373. Jameson, D.A. 1971. Optimum stand selection for juniper control on southwestern woodland ranges. Journal of Range Management 24:94–99.**

Equations describe relationships between herbage production and pinyon-juniper overstory with different grass growth-forms and soils. The equation model used is a 5-parameter transition sigmoid growth curve.

**374. Jameson, D.A.; Dodd, J.D. 1969. Herbage production differs with soil in the pinyon-juniper type of Arizona. USDA Forest Service, Research Note RM-131.**

Production on Springerville soils was similar to production on Gem and Tortugas soils when few trees are present, but Springerville soils produced much less with appreciable tree cover. Differences in soils were not due to soil moisture, nitrogen, or phosphorus.

**375. Kruse, W.H. 1970. Temperature and moisture stress affect germination of Gutierrezia sarothrae. Journal of Range Management 23:143–144.**

Germination of broom snakeweed seed was found best at 60–70 °F temperature and was inversely related to moisture stress.

**376. Kruse, W.H. 1983. Herbage response to strip-cutting a ponderosa pine watershed in central Arizona. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

The effects of strip-cutting pine overstory on understory plant productivity was evaluated. Relationships of 2 soil types and 2 aspects on productivity and how these relationships affected recovery of the understory plant community was also determined.

**377. Lavin, F.; Johnsen, T.N., Jr. 1975. Forage shrub adaption trials at three pinyon-juniper sites. USDA Agriculture Research Service, Publication W-29.**

Initial growing season results of an adaptation study entailing greenhouse, nursery, and field investigations on 40 accessions of 15 forage shrub species are reported. Accessions transplanted varied in germination speed, initial vigor, field growth, grazing proneness, and frost tolerance.

**378. Pearson, H.A. 1964. Studies of forage digestibility under ponderosa pine stands. Society of American Foresters Proceedings 1964:71–73.**

A logarithmic equation describing herbage production as a function of ponderosa pine overstory density is given for experimental range units in north central Arizona.

**379. Pearson, H.A. 1965. Low-cost constant-temperature water bath. Journal of Range Management 18:149–150.**

A low-cost constant-temperature water bath used as an incubating system for determining *in vitro* digestibility of range forage is described.

**380. Pearson, H.A. 1967a. Effects of delays in inoculum collection on artificial rumen digestabilities. Journal of Range Management 20:332–333.**

Results of artificial rumen digestion studies of range forage with different delays in inoculum collection are presented.

**381. Pearson, H.A. 1967b. Cattle diet digestabilities determined from components. Journal of Range Management 20:405–406.**

*In vitro* digestibility analyses of individual forage species in the cattle diet, and their relationship to digestibility of the cattle diet mixture is presented.

**382. Pearson, H.A. 1967c. Phenology of Arizona fescue and mountain muhly in the northern Arizona ponderosa pine type. USDA Forest Service, Research Note RM-89.**

Growth rates of Arizona fescue leaves as related to percent ponderosa pine canopy cover is presented in tabular form.

**383. Pearson, H.A. 1967d. Range animal nutrition. In: Proceeding of the 5th West Texas Range Management Conference, Texas Technical College, Lubbock, Special Report 3, pp. 66–82.**

Nutrients available for livestock production differ according to forage species, season of growth, plant parts, and location. These differences to a great extent determine animal intake. Digestible forage consumed can be used to estimate animal production more efficiently than forage use alone.

**384. Pearson, H.A. 1970. Digestibility trials: In vitro techniques. In: Range and wildlife habitat evaluation—a research symposium, May, 1968, Flagstaff and Tempe, Arizona. USDA Miscellaneous Publication 1147, pp. 85–92.**

*In vitro* fermentation methodology was selected for estimating nutritive value of forage because of its simplicity and economy. Procedures of technique are presented.

**385. Pearson, H.A. 1972. Estimating cattle gains from consumption of digestible forage on ponderosa pine range. Journal of Range Management 25(1):18–20.**

*In vitro* digestibility measurements reduced the variability in estimating cattle gains from forage intake measurements. The daily digestible forage intake requirements of range cattle appeared similar to the requirements of cattle in feedlots.

**386. Pearson, H.A. 1973. Calculating grazing intensity for maximum profit on ponderosa pine range in northern Arizona. Journal of Range Management 26(4):277–278.**

The profit formula is based on forage production, digestibility and use, animal weight and daily gain, costs per animal day, and beef prices. Rangeland producing 500 to 1,000 lbs of forage/acre would produce maximum profit with moderate use.

**387. Pearson, H.A.; Mann, J.F.; Howard, D.A. 1971. Timing use of cool- and warm- season grasses on pine ranges. Journal of Range Management 24:162–163.**

A grazing system designed to establish the earliest time when animals could enter the range without undue damage to Arizona fescue, provide periods of nonuse for growth and development of both Arizona fescue and mountain muhly, obtain increased use balanced between the 2 forage species, and maintain beef production is presented.

**388. Reid, E.H. 1964. Forage production in ponderosa pine forests. Society of American Foresters Proceedings 1964:61–64.**

A discussion of forage values in pine forests, and how they are influenced by tree overstory, logging, and seeding of logged and burned areas is presented.

**389. Reynolds, H.G. 1962. Some characteristics and uses of Arizona's major plant communities. Journal of the Arizona Academy of Science 2:62–71.**

A literature review, including a description of the relationships between herbage production and tree overstory, is presented for different vegetation types in Arizona.

## Silviculture

**390. Avery, C.C.; Larson, F.R.; Schubert, G.H. 1976. Fifty-year records of virgin stand development in southwestern ponderosa pine. USDA Forest Service, General Technical Report RM-22.**

Ten periodic inventories of an unburned virgin tract of more than 3,000 trees are documented by individual tree records; 2.5-acre subplot summaries of basal area and tree census data and composite stand tables that display census data, mortality data and causes, net periodic basal area, volume, and diameter growth.

**391. Biondi, F. 1987. Influence of Gambel oak on radial growth of southwestern ponderosa pine: A dendrochronological study. MS Thesis, University of Arizona, Tucson, Arizona.**

Radial growth of sampled trees fluctuated around a relatively constant level during 1936–1985. Differences in this level were related to differences in competition, presence of oak, age of ponderosa pine trees, and site index. Pine growth increased with increasing oak presence and decreasing intraspecific competition.

**392. Biondi, F.; Klemmedson, J.O.; Kuehl, R.O. 1992a. Dendrochronological analysis of single-tree interactions in mixed pine-oak stands of central Arizona, U.S.A. Forest Ecology and Management 48:321–333.**

Interactions between ponderosa pine and Gambel oak trees are described. Diameter growth of dominant young-growth pine increased with increasing Gambel oak presence. Pine radial growth was negatively related to intraspecific competition but not to interspecific competition between pines and oaks.

**393. Biondi, F.; Klemmedson, J.O.; Kuehl, R.O. 1992b. Tree-ring analysis of pine- oak interactions in central**

**Arizona. In: Proceedings of the International Dendrochronological Symposium, Lund, LUNDQUA Report 34, Sweden.**

Dendrochronological techniques revealed that radial growth of sampled pine and oak trees fluctuated around a relatively constant level between 1936 and 1985. Observed differences were attributed to competition, oak presence, pine age, and site index.

**394. Clary, W.P. 1987. Selection of silvicultural systems for forage production. In: Ponderosa pine: the species and its management. (Abstracts). September 29–October 1987, Spokane, Washington, United States Forest Service, Washington State University, University of Idaho, and Society of American Foresters, p. 30.**

Ponderosa pine is the most widespread Western United States forest type, and it encounters a diversity of environmental conditions. A discussion of how to manage the forest for timber and other values, such as forage production, is presented.

**395. Clary, W.P. 1988. Silvicultural systems for forage production in ponderosa pine forests. In: Baumgartner, D.M. and J.E. Lotan, compilers. Ponderosa pine the species and its management: symposium proceedings, September 29–October 1, 1987, Spokane, Washington, United States Forest Service, Washington State University, University of Idaho, and Society of American Foresters. pp.185–191.**

Ponderosa pine is the most widespread Western United States forest type, and it encounters a diversity of environmental conditions. A discussion of how to manage the forest for timber and other values, such as forage production, is presented.

**396. Clary, W.P.; Tiedemann, A.R. 1992. Ecology and values of Gambel oak woodlands. In: Ffolliott, P.F., G.J. Gottfried, D.A. Bennet, C. Hernandez, V. M. Hernandez C., A. Ortega-Rubio, and R.H. Hamre, Technical Coordinators. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico. April 27–30, 1992. Sierra Vista, Arizona, USDA Forest Service General Technical Report RM-218, pp. 87–95.**

Gambel oak is an important component in the vegetative cover of the Western United States. This species, providing watershed stability, wildlife habitat, fuelwood, and a variety of other values, has considerable economic, conservation, and esthetics values when managed in place.

**397. Ffolliott, P.F. 1981. Forest ecosystems in southwestern United States. In: Ffolliott, P.F., and S. Gallina, eds. Deer biology, habitat requirements, and management in western North America. Instituto de Ecologia, A. C., Mexico, D. F., Publication 9, pp. 57–76.**

Descriptions of mixed conifer forests, ponderosa pine forests, and pinyon-juniper woodlands, including overstory species compositions, lesser vegetation, wildlife and fishery resources, and recreational use, are presented. The Beaver Creek Biosphere Reserve contains representative areas in the latter 2 ecosystems.

**398. Ffolliott, P.F.; Baker, M.B., Jr. 1977. Characteristics of Arizona ponderosa pine stands on sandstone soils. USDA Forest Service, General Technical Report RM-44.**

Limited information from stands in north central Arizona indicates that annual water yield is about 25% less than that from stands on volcanic soils. In addition, herbage production is lower, even though forest densities are less, and forest site index is higher.

**399. Ffolliott, P. F.; Gottfried, G.J. 1991. Natural tree regeneration after clearcutting in Arizona's ponderosa pine forests: Two long-term case studies. USDA Forest Service, Research Note RM-507.**

After the treatments, clearcutting resulted in limited natural regeneration. Therefore, clearcuts must be planted soon after treatment when the management objective is to maintain a forest structure.

**400. Ffolliott, P.F.; Solomon, R.M. 1976. Distributions of ponderosa pine forest densities on the Salt-Verde River Basin. Agriculture Experiment Station, Technical Bulletin 227, University of Arizona, Tucson, Arizona.**

The proportions of forested areas supporting minimum timber densities that can affect the yield of natural resource products and uses are presented. This information supplements the available descriptions of ponderosa pine forests to assist in assessment of potential productivity of natural resources. Applications of the survey information are also given.

**401. Ffolliott, P.F.; Thompson, J.R. 1976. Snow damage in Arizona ponderosa pine stands. USDA Forest Service, Research Note RM-322.**

Snow damage in 3 cutover ponderosa pine stands was evaluated following a year of record snowfall. Susceptibility to bending decreased as diameter at breast height increased. Dense sapling stands suffered significantly more damage than thinned stands. Thinning early in the sapling stage is recommended to reduce the snow damage potential.

**402. Ffolliott, P.F.; Worley, D.P. 1973. Forest stocking equations: Their development and application. USDA Forest Service Research Paper RM-102, 8 p.**

Equations relating proportions of a forest stocked to minimum basal area levels can be defined by regression analysis. Equations can be used to help evaluate land treatment potential, determine treatment feasibility, and set operating priorities.

**403. Gottfried, G. J.; Ffolliott, P.F. 1993. Silvicultural prescriptions for sustained productivity of the southwestern pinyon-juniper and encinal woodlands. In: Manzanilla, D. Shaw, C. Aguirre-Bravo, L. Iglesias Gutierrez, and R.H. Hamre, technical coordinators. Making sustainability operational: Fourth Mexico/U.S. symposium. USDA Forest Service, General Technical Report RM-240, pp. 185–192.**

Characteristics and uses of the woodland types are described, and silvicultural methods to enhance and sustain productivity for multiple benefits are discussed. Silvicultural prescriptions can benefit fuelwood production,

forage production, wildlife habitats, watershed protection, and recreation.

**404. Gottfried, G.J.; Ffolliott, P.F. 1995. Stand dynamics on upper elevation pinon- juniper watersheds at Beaver Creek, Arizona. In: Shaw, D.W., E.F. Aldon, and C. LoSapio, tech. coords. 1995. Desired future conditions for pinyon-juniper ecosystems. USDA Forest Service, General Technical Report RM-258, pp. 38–45.**

Repeated inventories over 24 years in north central Arizona provided information about the distribution of trees by diameter class and volume growth. Stand density is increasing but at a slow rate.

**405. Heidmann, L.J.; Larson, F.R.; Reidveld, W.J. 1977. Evaluation of ponderosa pine reforestation techniques in central Arizona. USDA Forest Service, Research Paper RM-190.**

Regeneration studies, seeding, planting, and natural, over the past 15 years in several areas indicate that direct seeding offers little hope of success. Failure is attributed to seasonal drought intensified by clay soils and competing vegetation. Tree planting has been consistently more successful.

**406. Jameson, D.A.; Johnsen, T.N., Jr. 1964. Ecology and control of alligator juniper. Weeds 12(2):140–142.**

Alligator juniper, considered a weed tree on range and timber areas in Arizona and New Mexico, sprouts from stems, roots, and buds on the root crown when the top is destroyed. Mechanical control requires that the root crown be removed from the soil; chemical control by treating the stumps shows promise.

**407. Johnsen, T.N., Jr.; Clary, W.P.; Ffolliott, P.F. 1969. Gambel oak control on the Beaver Creek pilot watershed in Arizona. USDA Agriculture Research Service, ARS 34-104.**

Dormant-basal applications of 12 lbs of an ester of 2,4,5-T in diesel oil killed many plant parts and repressed sprouts. Applications of pelleted fenuron also reduced Gambel oak sprouts. Other herbicides tested had little effect.

**408. Larson, F.R. 1980. Pinyon-juniper. In: Eyre, F.H., editor. Forest cover types of the United States and Canada. Washington D.C., Society of American Foresters, pp. 116–117.**

Definition and composition, geographic distribution, ecological relationships, and variants and associated vegetation of type are presented.

**409. Larson, F.R.; Ffolliott, P.F.; Clary, W.P. 1970. Distribution of dwarf mistletoe in ponderosa pine stands on the Beaver Creek watershed. USDA Forest Service, Research Note RM-175.**

Frequency of dwarf mistletoe infection was highest on upper slopes and in areas of intermediate site index. Frequency was not related to aspect, slope steepness, or tree diameter.

**410. McCulloch, C.Y.; Wallmo, O.C.; Ffolliott, P.F. 1965. Acorn yield of Gambel oak in northern Arizona. USDA Forest Service, Research Note RM-48.**

Acorn production of 94 trees in a 6-year period indicated 3 years of heavy production, 2 years of low production, and 1 year of no production. Acorn yield was related to diameter classes within 3 vigor classes. Gambel oak with 80% or more of their crown alive up to 15 inches in diameter at breast height should be retained for maximum acorn production.

**411. McMurtray, M. 1979. Effects of silvicultural practices on Arizona ponderosa pine stem quality. MS Thesis, University of Arizona, Tucson, Arizona.**

Changes in the occurrences of sweep, crook, forking, log knots, and other stem quality features are described in relation to seed tree, shelterwood, group selection, and uniform thinning treatments on the Beaver Creek watersheds. Rates of tree mortality following these silvicultural practices were comparably low relative to observed mortality in the region.

**412. Myers, C.A. 1962. Twenty-year growth of Utah juniper in Arizona. USDA Forest Service, Research Note RM-71.**

Growth of Utah juniper on a 4-acre plot in north central Arizona is reported by stump diameter class.

## Simulation Techniques

**413. Carder, D.R. 1976. Development and trial application of a prototype family of ecosystem component simulation models for land and water management. In: Earth Sciences Symposium Proceedings, Fresno, California, November 11, 1976.**

Improved methods for managers to use in predicting biophysical and social-economic effects of forest management alternative, and in evaluating the tradeoffs among these alternatives are presented.

**414. Carder, D.R.; Larson, F.R.; Rogers, J.J.; Rasmussen, W.O.; Ffolliott, P.F. 1977. Ecosystem analysis for watershed management. Arizona Watershed Symposium 21:22–25.**

The purpose of the Multi resource management research program on Beaver Creeks is explained in relation to advance knowledge and technology for multiple-use management of forest watersheds.

**415. Ffolliott, P.F. 1990. Multiple resource simulation models. In: Wang, L. editor. Lecture notes for international training course on forest hydrology modeling. UNESCO, Beijing Forestry University, Beijing, People's Republic of China, pp. 37–41. (Chinese)**

A synthesis of multiple resource simulation models is outlined. Data sets obtained on the Beaver Creek watershed are used as inputs to the models. How this approach might be applied in China is described.

**416. Ffolliott, P.F. 1993. Hydrological and multi-resource simulation models: Applications in mountainous areas. In: Proceedings of the International Symposium on Hydrology of Mountainous Areas. National Institute of Hydrology, Shilma, India, May 28–30, 1992, pp. 315–329.**

A group of computer simulation models developed in the montane forests of the Southwestern United States is

described to illustrate the use of the models in simulating effects of land-management modifications in mountainous areas. The framework of the models can also be applied to other world regions.

**417. Ffolliott, P.F.; Guertin, D.P. 1988. YIELD II: An interactive computer model to simulate water yield in southwestern ecosystems. In: Proceedings of the 1988 International Symposium on Modeling Agriculture, Forest, and Rangeland Hydrology. American Society of Agricultural Engineers, Chicago, Illinois, December 12–13, 1988, pp. 72–78.**

Formulation, applications, and specifications of an updated modeling version is presented. The model is comprised of components to simulate water yield from rainfall events, snowmelt, or combinations of these processes.

**418. Ffolliott, P.F.; Guertin, D.P. 1990. Applications of forest hydrology and multiple-resource simulation models. In: Ffolliott, P.F., and D.P. Guertin, eds. Proceedings of a workshop: Forest hydrological resources in China—An analytical assessment. U.S. Department of State, Publication 9829, pp. 77–88.**

A system of simulation models is described in terms of its applications in planning and evaluation of land-management practices potentially impacting forest hydrology and multiple-resource management. Illustrative input requirements were derived from data sets obtained on the Beaver Creek watershed. Procedures to localize the technical coefficients in the models for applications in China are presented.

**419. Ffolliott, P.F.; Guertin, D.P.; Fogel, M.M. 1990. An interactive computer model to simulate water quality of streamflow from forested watersheds in Arizona. In: Riggins, R.E., E.B. Jones, R. Singh, and P.A. Richard editors, Proceedings of the symposium on watershed planning and analysis in action. American Society of Civil Engineers, Durango, Colorado, July 9–11, 1990, pp. 285–292.**

A model that simulates concentrations of dissolved chemicals in snowmelt-runoff is presented. Model applications include simulation of effects of watershed management practices on dissolved chem cal concentrations, identifying practices that are "safe" in terms of adherence to water quality standards, and estimating magnitudes of nutrient flows from watersheds of specified conditions.

**420. Ffolliott, P.F.; Guertin, D.P.; Rasmussen, W.O. 1988a. A model of snowpack dynamics in forest openings. Hydrology and Water Resources in Arizona and the Southwest 18:1–6.**

A simulation model is developed to analyze snowpack dynamics in forested conditions. The model allows managers to estimate impacts of alternative forest practices on snowpack accumulation and melt patterns.

**421. Ffolliott, P.F.; Guertin, D.P.; Rasmussen, W.O. 1988b. Simulating the impacts of fire: A computer program. Environmental Management 12:809–814.**

Formulation, application, and specifications of the simulation model are presented. Vegetative, wildlife, and hydrologic components are considered.

**422. Ffolliott, P.F.; Rasmussen, W.O. 1979a. An interactive model of snowpack accumulation and melt dynamics in forest conditions. In: Colbeck, S. editor, Proceedings of a meeting on modeling snow cover runoff. U.S. Army Corps of Engineering, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, September 25–28, 1978, pp. 359–368.**

The simulation model considers snowpack conditions before a management change and following either a thinning practice or a clearing. Input requirements are generated from readily available data sets.

**423. Ffolliott, P.F.; Rasmussen, W.O. 1979b. Use of remote sensing data to interactively simulate wildlife habitat quality. In: Berger, M. E., D. W. Carneggie, M. Felcher, A. Marmelstein, G. A. Thorley, and G. Watson, eds. Application of remote sensing data to wildlife Management. The PECORA IV Symposium, Sioux Falls, South Dakota, October 10–12, 1978, National Wildlife Federation, Scientific and Technical Series 3: 294–299.**

A prototype simulation model, called HABRAN (HABitat RANking), is described. Using inputs of crown closure obtained from aerial imagery, ranked response predictions are synthesized, summarized, and arrayed as pattern recognition models.

**424. Ffolliott, P. F.; Rasmussen, W.O. 1983. Measurement and simulation of changes in timber quality features. In: Bell, J. F., and T. Atterbury. Proceedings of an international conference on renewable resources inventories for monitoring changes and trends. Society of American Foresters, Corvallis, Oregon, August 15–19, 1983, pp. 197–201.**

Through evaluations of probability functions, changes in timber quality features are simulated. Although applicable to Southwestern ponderosa pine, the framework of the simulator can be useful elsewhere.

**425. Ffolliott, P.F.; Rasmussen, W.O.; Guertin, D.P. 1987. Simulating the impacts of fire: A hydrologic component. Hydrology and Water Resources in Arizona and the Southwest 17:23–28.**

Formulation, application, and future development of a simulation model to estimate the benefits and detrimental impacts of fire are described. Changes in annual streamflow and water quality parameters are considered.

**426. Ffolliott, P.F.; Rasmussen, W.O.; Guertin, D.P. 1988. STAND: An interactive model to simulate the growth and yield of woodlands in the Southwest. In: Ek, A.R., S.R. Shifley, and T.E. Burk, tech. Coords. Forest growth and modeling prediction. USDA Forest Service, General Technical Report NC-120, pp. 968–975.**

The simulation model predicts the impacts of land-management practices on pinyon-juniper and oak woodlands. Predictions can be obtained for initial conditions, at some point in the future under the initial land-management practice, or after implementation of alternative management practices.

**427. Jeton, A.E. 1990. Vegetation management and water yield in a southwestern ponderosa pine watershed: An**

**evaluation of three hydrologic simulation models. MS Thesis, University of Arizona, Tucson, Arizona.**

This report addresses the problem of evaluating the reliability of different hydrologic simulation models when assessing the impact of vegetation management on water yield and uses data from pine watershed in north central Arizona for testing the 3 models.

**428. Larson, F.R. 1975a. Simulating growth and management of ponderosa pine stands. PhD Dissertation, Colorado State University, Fort Collins, Colorado.**

A growth and management simulator for ponderosa pine stands is developed in a computer-user interactive framework. The model is capable of estimating growth over the range of pure pine stands with a minimum amount of input.

**429. Larson, F.R. 1975b. Simulating growth and management of ponderosa pine stands. In: Meadows, J., B. Bare, K. Ware, and C. Row, editors. Systems Analysis and Forest Resources. Society of American Foresters, Bethesda, MD., pp. 211–221.**

A growth and management model for ponderosa pine stands is developed that is capable of estimating growth over the range of pure ponderosa pine stands with a minimum amount of input.

**430. Larson, F.R. 1976. Simulator model use in determining output by alternatives. USDA Forest Service, Region 3 Land Use Planning Symposium, Albuquerque, MN. 28 p.**

An improved version of the PIPO model is presented, and its use for predicting outcomes using various management schemes is discussed. This model has equations for predicting herbage production, water runoff, and sediment production from watersheds on basalt-derived soils.

**431. Larson, F.R.; Minor, C.O. 1983. AZPIPO: A simulator for growth and yield of ponderosa pine in Arizona. Arizona Forestry Notes No. 20, School of Forestry, Northern Arizona University.**

A simulator is developed from a literature review of pine growth and development. Field data collected from national forests and Indian Reservations in Arizona were used to verify and improve the literature-derived functions. The simulator is designed to assist forest managers when growth and yield predictions are necessary.

**432. Larson, F.R.; Ffolliott, P.F.; Rasmussen, W.O.; Carder, D.R. 1979. Estimating impacts of silvicultural management practices on forest ecosystems. In: Best Management Practices for Agriculture and Silviculture, Proceedings of the 1978 Cornell Agriculture Waste Management Conference, pp. 281–294.**

A prototype family of computer simulation models, called ECOSIM, is being developed to help forest managers and land-use planners estimate the impact of silvicultural management practices on forest ecosystems.

**433. Li, R.M.,; Simons, D.B.; Carder, D.R. 1976b. Computer simulation of storm water and sediment hydrographs from small watersheds. In: Proceedings of the 1976 Summer Computer Simulation Conference, Washington, D.C. 7 p.**

Model formation and test results for a numerical computer model using formulations of basic physical processes to determine water and sediment hydrographs and yields from small watershed are presented.

**434. Mattern, D.E. 1989. Hydrologic simulation of pinyon-juniper woodlands in Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

A physically-based, user-friendly computer simulation model that predicts surface runoff from cleared and uncleared watersheds on Beaver Creek is described. The simulator outputs runoff on a daily basis from knowledge of the woodland overstory conditions, soil-survey information, and daily values for precipitation and temperature. No significant differences were found between predicted and observed values.

**435. McTague, J.P. 1991. Chapter 3. Tree growth and yield in southwestern ponderosa pine forests. In: Tecle, A. and W.W. Covington, Technical editors. 1991. Multi resource management of southwestern ponderosa pine forests: The status of knowledge. USDA Forest Service, Southwestern Region Report. pp. 24–120.**

There are currently 5 models available for estimation of ponderosa pine growth and yield in the Southwest. Each model contains a unique approach to predicting the effect of stand structure, site quality, and stand density on tree and stand growth. The strengths and weaknesses of each model are presented along with a critique of methods for determining stand density and estimating site quality.

**436. Rasmussen, W.O.; Ffolliott, P.F. 1979. An interactive model of suspended sediment yield on forested watersheds in central Arizona. Hydrology and Water Resources in Arizona and the Southwest 9:43–47.**

Suspended sediment concentrations following summer rainfall events were simulated. Outputs included total weight of sediments and maximum sediment concentration for the event simulated.

**437. Rasmussen, W.O.; Ffolliott, P.F. 1980. Prediction of the chemical quality of streamflow by an interactive computer model. Hydrology and Water Resources in Arizona and the Southwest 10:93–98.**

Predictions of instantaneous concentrations of 11 dissolved chemical constituents, total soluble salts, and conductivity of streamflow from snowmelt were obtained. Daily yields of constituents were also obtained in terms of total weight.

**438. Rasmussen, W.O.; Ffolliott, P.F. 1981a. Computer simulation problems for resource management instruction. Journal of Forestry 79:612.**

A problem set for use by upper-level undergraduate and graduate students is described. The problem set is supplemented by information about available computer simulation models.

**439. Rasmussen, W.O.; Ffolliott, P.F. 1981b. Prediction of water yield using satellite imagery and a snowmelt simulation model. In: Deutsch, M., D. R. Wiesnet, and A. Rango, eds. Satellite hydrology. American Water Resources Association, Minneapolis, Minnesota, pp. 193–196.**

The computer model described uses satellite imagery to delineate the areal extent to the snow-covered area near peak seasonal snowpack accumulation. A degree-day snowmelt technique was used to predict daily melt, with daily streamflow being computed from recession analysis.

**440. Rasmussen, W.O.; Ffolliott, P.F. 1981c. Simulation of consequences of implementing alternative natural resources policies. In: Ffolliott, P.F., and G. Halffter, tech. coords. Social and environmental consequences of natural resources policies, with special emphasis on Biosphere Reserves: Proceedings of the international seminar. USDA Forest Service, General Technical Report RM-88, pp. 41–43.**

A group of computer simulation models to aid natural resource policy makers in estimating the consequences of implementing alternative policies is described. An example of the use of these models is also presented.

**441. Rasmussen, W.O.; Ffolliott, P.F. 1983. A model to predict snag development. The Wildlife Society Bulletin 11:291–292.**

The model, called SNAG, operates with a timber growth and yield model to predict the annual rate of tree mortality from natural causes. The length of time that dead trees (snags) remain standing is simulated.

**442. Reich, B.M. 1971. Feasibility study of conceptual models for Beaver Creek hydrology. Unpublished Report, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A review of conceptual models is presented to provide familiarity with some specifics of these models and also to provide an understanding of their applications particularly as related to the hydrologic regimes on Beaver Creek in north central Arizona.

**443. Rogers, J.J. 1973. Design of a system for predicting effects of vegetation manipulation on water yield in the Salt-Verde Basin. PhD Dissertation, University of Arizona, Tucson, Arizona.**

The methodology of a mathematical system to develop, implement, and test a model of the hydrologic behavior of managed ecosystems in ponderosa pine forests is outlined. Data sets from the Beaver Creek watershed were used to study the effects of vegetation manipulations on water yields.

**444. Rogers, J.J.; Baker, M.B., Jr.; Prosser, J.M.; Kulongowski, B. 1979. ECOSIM II-A system for simulating onsite effects of silvicultural management alternatives. A final report to the Southeastern Environmental Research Center, Office of Research and Development, U.S. Environmental Protection Agency.**

An interactive model called ECOSIM is presented that simulates the effects of silvicultural prescriptions on forest growth, mortality, yield, stand structure, herbage production, forest floor accumulation and decomposition, fuel bed description, water and sediment yield, wildlife habitat, and near-view scenic quality. Calibration, testing, and evaluation of the model is currently being done.

**445. Rogers, J.J.; Prosser, J.M.; Garrett, L.D. 1981. Modeling onsite Multi resource effects of silvicultural management prescriptions. In: Vodak, M.C., W.A. Leuschner, and D.I. Navon, eds.Proceedings of IUFRO Forest Management Symposium, [Blacksburg, VA., August 18–20, 1980]. Publ. FWS-1-81, January, pp. 107–117.**

An interactive prototype system to estimate Multi resource outputs from Southwestern forests and woodlands under alternative management regimes is described. The system simulates forest growth and yield including mortality, herbage yield, water yield, soil loss, forest floor accumulation, and decomposition of snags, logs and debris, wildlife habitat, and near-view scenic quality.

**446. Rogers, J.J.; Prosser, J.M.; Garrett, L.D. 1982. ECOSIM: A prototype system for estimating Multi resource outputs under alternative forest management regimes. In: Corcoran, T. and W. Heij, co-editors, Proceedings IVII IUFRO World Congress, Working Party Planning and Control of Forest Operations S3.04.01. [Kyoto, Japan, Sept. 6–17, 1981]. Life Sci. and Agric. Exp. Stn., Univ. of Maine, Orono. Misc. Rep. 264. pp. 122–127.**

An interactive prototype system to estimate multi resources outputs from Southwestern forests and woodlands under alternative management regimes is presented. The system simulates forest growth and yield including mortality, herbage yield, water yield, soil loss, forest floor accumulation, and decomposition of snags, logs and debris, wildlife habitat, and near-view scenic quality.

**447. Rupp, D.E. 1995. Spatially-varied, stochastic water yield modeling of an upland watershed. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

A water-yield model was developed as a function of time-variant climatic and spatially-variant terrestrial features of a given watershed. Because the variables require different modeling methods, the model is split into climate and terrestrial components.

**448. Rupp, D.E.; Tecle, A. 1995. A stochastic model for simulating daily temperature and humidity on a ponderosa pine type watershed. Hydrology and Water Resources in Arizona and the Southwest 22–25:101–108.**

A model was constructed to simulate daily maximum and minimum temperatures and daily vapor pressure deficits throughout the cold season for a site in the pine type on the Beaver Creek watershed in north central Arizona. The synthetic temperature and vapor pressure data were used as inputs to a cold-season water-yield model designed for use in upland watersheds.

**449. Tecle, A.; Dykstra, D.P.; Covington, W.W.; and Garrett, L.D. 1990. Proposed methodology for soil loss prediction from southwestern forests. Hydrology and Water Resources in Arizona and the Southwest. 20:113–129.**

Methods for predicting water-induced erosion and sediment yield are explored and reviewed. Models for further development to make them applicable to Southwestern forest conditions are identified.

**450. Simons, D.B.; Li, R.M.; Eggert, K.G. 1977. Storm water and sediment runoff simulation for upland watersheds using analytical routing techniques. Vol. I, Water Routing and Yield, Final Report CER 77-78, DBS-RML-KGE16 Pre-**

**pared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

In this model, a watershed is represented by a channel and 2 contributing planes or a combination of a 2 plane watershed and a single plane watershed connected by a channel system. This simpler representation of the watershed provides for easier application but may create problems if the watershed is extremely nonhomogeneous or anisotropic.

**451. Simons, D.B.; Li, R.M.; Fullerton, W.T.; Grindeland, T.R. 1981. Storm water and sediment runoff simulation for a system of multiple watersheds. Volume II. Sediment routing and yield. Final Report Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A mathematical model to simulate water and sediment hydrographs from large watersheds was developed based on a simplified watershed geometry. Test results from Walnut Gulch show satisfactory agreement between simulated and measured hydrographs.

**452. Simons, D.B.; Li, R.M.; Spronk, B.E. 1978. Storm and water and sediment runoff simulation for a system of multiple watersheds. Vol. I, Water Routing and Yield. Final Report CER77-78DBS-RML-BEST47 Prepared by Colorado State University, Fort Collins, Colorado, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

This multiple watershed model subdivides a large watershed into homogeneous response units as dictated by basin geometry and physical characteristics. The system of planes, channels, and subwatersheds were designed to represent an entire basin. The hydrographs from each response unit are simulated and then combined to obtain a hydrograph for the entire watershed.

**453. Simons, D.B.; Shiao, L.Y.; Li, R.M.; Eggert, K.G. 1977. Storm water and sediment runoff simulation for upland watersheds using analytical routing techniques. Vol. II, Sediment Yield, Colorado State University, Report CER77- 78DBS-RML-KGE17. Prepared for USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

A mathematical model to simulate water and sediment hydrographs from large watersheds was developed based on a simplified watershed geometry. Test results from Walnut Gulch show satisfactory agreement between simulated and measured hydrographs.

**454. Solomon, R.M.; Ffolliott, P.F.; Baker, M.B., Jr.; Thompson, J.R. 1976. Computer simulation of snowmelt. USDA Forest Service, Research Paper RM-174.**

A modification of a previously developed computer model of snowmelt provides for simulating intermittent snowpack conditions and is a more generalized model. Simulated snowmelt depends on 4 daily input variables: maximum and minimum temperatures, precipitation, and shortwave radiation or percent cloud cover.

**455. Tecle, A.; Rupp, D.E. 1995. Stochastic, event-based, and spatial modelling of cold-season precipitation. In: Guy, B.T. and J. Barnard, editors. Mountain Hydrology, Peaks and Valleys in Research and Applications, May 16–19, 1995, Vancouver, B.C. Canada. pp. 171–182.**

An event-based water-yield model that takes advantage of current GIS technology was developed for use on upland watersheds in Arizona. A cold-season precipitation model was developed to generate inputs into the water model. The precipitation model includes the temporal and spatial characteristics of the precipitation in an area.

**456. Trotta, P.D.; Rogers, J.J.; Vandivere, W.B. 1979. Impact of development on streamflows. Hydrology and Water Resources in Arizona and the Southwest 9:109–118.**

A simulation model (ECOWAT) was used to quantified the impacts of development on stream flows and to determine how the regulating effect of the watershed on stream flow is influenced by changes in land use.

## Snow

**457. Aul, J.S. 1975. Use of areal snow cover measurements to develop snowmelt- runoff relationships for Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

Snow cover measurements obtained from ERTS-1 imagery were used to predict subsequent snowmelt-runoff. Alternative methods of interpreting the imagery are also discussed.

**458. Aul, J.S.; Ffolliott, P.F. 1975. Use of areal snow cover measurements from ERTS-1 imagery in snowmelt-runoff relationships in Arizona. In: Rango, A., editor. Operational applications of satellite snowcover observations. National Aeronautics and Space Administration, NASA SP-391, pp. 103–112.**

An analysis of methods for interpreting ERTS-1 imagery to measure areal snow cover and the relationships between areal snow cover and runoff is presented. Forecasting snowmelt-runoff relationships is also discussed.

**459. Bohren, C.F. 1973. Theory of radiation heat transfer between forest canopy and snowpack. In: Proceedings of Symposium on the Role of Snow and Ice on Hydrology, UNESCO, World Meteorological Organization and International Association of Hydrological Sciences, Banff, Alberta, Canada, June 1972, pp. 165– 173.**

This report is a theoretical study of short- and long-wave solar radiation exchanges between snowpacks and forest canopies. Short- and long-wave radiation on snowpack vary as functions of a forest canopy structure. Models developed describe the effects of manipulating forest canopies on the radiation components and, consequently, on the buildup, physical conditions, and ablation of snowpacks.

**460. Bohren, C.F.; Barkstrom, B.R. 1974. Theory of the optical properties of snow. Journal of Geophysical Research 79:4527–4535.**

This is one of a series of reports on the theoretical study of the interactions between snowpack conditions and forest overstories. Optical properties of a snowpack were calculated. These predictions agreed with other experimental data.

**461. Bohren, C.F.; Thorud, D.B. 1973. Two theoretical models of radiation heat transfer between forest trees and snowpacks. Agricultural Meteorology 11:3–16.**

This paper is a theoretical study of the interactions of snowpack conditions and forest overstories. Short- and long-wave radiation on snowpack vary as functions of a forest canopy structure. Models developed describe the effects of manipulating forest canopies on the radiation components and, consequently, on the buildup, physical conditions, and ablation of snowpacks.

**462. Delk, R. 1969. Snow distribution patterns under various stand densities of ponderosa pine. MS Thesis, University of Arizona, Tucson, Arizona.**

Snow depths, water equivalents, and densities are related to overstory density conditions expressed in terms of number of trees and basal area per acre. Management implications are also presented.

**463. Ffolliott, P.F. 1970. Characterization of Arizona snowpack dynamics for prediction and management purposes. PhD Dissertation, University of Arizona, Tucson, Arizona.**

Inventory-prediction equations describing snowpack content as functions of readily available or easily obtained inventory variables are presented. Variables to index interception of snowfall, obstruction of direct beam solar radiation, and re-radiation from trees onto snowpacks are included. Snowpack management guidelines to meet a range of specified objectives are also presented.

**464. Ffolliott, P.F. 1983. Time-space effects of openings in Arizona forests on snowpacks. Hydrology and Water Resources in Arizona and the Southwest 13:17–20.**

Effects of openings are described in terms of readily available variables. Empirically derived relationships are presented to assist watershed managers in determining spatial and temporal effects of forest openings on snowpack regimes.

**465. Ffolliott, P.F. 1985. Snowpack density: An index of snowpack condition. Hydrology and Water Resources in Arizona and the Southwest 15:1–6.**

Snowpack density is a useful index of the stage of snowpack ripening. A review of studies previously conducted to evaluate the usefulness of snowpack density for this purpose is presented.

**466. Ffolliott, P.F. 1986. Twenty-five years of snow research in Arizona: A preliminary report. Hydrology and Water Resources in Arizona and the Southwest 16:95–103.**

This review describes some of the possibilities for increasing snowmelt water yields. These research efforts have been aimed at the development of snow management guidelines to increase the amount of recoverable water from snowpacks on forested watersheds.

**467. Ffolliott, P.F. 1993. Snowpack dynamics in mountainous areas: Research findings in the southwestern Unite State. In: Proceedings of the International Symposium on Hydrology of Mountainous Areas. National Institute of Hydrology, Shilma, India, May 28–30, 1992, pp. 129–139.**

This review of snow research describes the possibilities for increasing snowmelt water yields. Studies have been concerned with basic snow hydrology, forest-snow relationships, and techniques of predicting the effects of management on snowpack water yields.

**468. Ffolliott, P.F.; Hansen, E.A. 1968. Observations of snowpack accumulation, melt, and runoff on a small Arizona watershed. USDA Forest Service, Research Note RM-124.**

Intensive measurements of snow and streamflow on a 425-acre watershed indicated that more than 90% of the snowpack left the watershed as runoff. Snow accumulation was inversely related to forest density, suggesting an opportunity for increasing snow accumulation through more intensive forest management.

**469. Ffolliott, P.F.; G.J. Gottfried, G.J.; Baker, M.B., Jr. 1989. Water yield from forest snowpack management: Research findings in Arizona and New Mexico. Water Resources Research 25:1999–2007.**

Snow in high-elevation forests is an important source of water for much of the arid Southwest. A review of snow management research over the past 25 years indicates some of the possibilities of increasing snowmelt water yields through forest management activities.

**470. Ffolliott, P.F.; Hansen, E.A.; Zander, A.D. 1965. Snow in natural openings and adjacent ponderosa pine stands on the Beaver Creek watersheds. USDA Forest Service, Research Note RM-53.**

Relationships between snow accumulation and melt patterns and forest overstory density conditions are presented. Slope and aspect were eliminated as much as possible to avoid confounding effects. Comparisons between measurements obtained with a snow tube and scale, and precipitation collected in standard gages were also made to describe the changes in snow accumulation in relation to distances from the edge of the tree canopies.

**471. Ffolliott, P.F.; Thorud, D.B. 1969. Snowpack density, water content, and runoff on a small Arizona watershed. Western Snow Conference 37:12–18.**

An average density of 0.37 gm cm [-3] represents ripe snowpack conditions for the watershed measured. The snowpack density measurements appeared to be normally distributed, while snowpack water content measurements were not. Relationships between snowpack density and water content and forest densities, elevation, and potential insolation were weak.

**472. Ffolliott, P.F.; Thorud, D.B. 1972. Use of forest attributes in snowpack inventory-prediction relationships for Arizona ponderosa pine. Journal of Soil and Water Conservation 27:109–111.**

Inventory-prediction equations describing snowpack accumulation as functions of readily available or easily obtained measurements of forest density and land form are presented. These equations include measurements assumed to index interception of precipitation, obstruction of direct-beam solar radiation, and radiation from trees onto the snowpack. Land form factors index the quantity of direct-beam solar radiation.

**473. Ffolliott, P.F.; Thorud, D.B. 1973. Describing Arizona snowpacks in forested condition with storage duration index. Progressive Agriculture in Arizona 25:6–7.**

The storage-duration index was developed for arbitrarily selected time periods by adding together snowpack water equivalent measurements made in successive surveys for the period. Maximum index values were obtained with large, initial storage followed by slow melting, while low, initial storage followed by rapid melting provided minimum index values.

**474. Ffolliott, P.F.; Thorud, D.B. 1974a. A technique to evaluate snowpack profiles in and adjacent to forest openings. Hydrology and Water Resources in Arizona and the Southwest 4:10–17.**

A technique for evaluating snowpack profiles in and adjacent to forest openings (strips) is presented. Application of the technique allows estimates of whether an increase or a decrease in snowpack water equivalents has occurred and defines the trade-offs between the estimated change and the forest removed in creating the opening.

**475. Ffolliott, P.F.; Thorud, D.B. 1974b. Development of forest management guidelines for increasing snowpack water yields in Arizona. Arizona Water Resources Project Information, Project Bulletin 7.**

Development of operational forest management guidelines for increasing water yields from snowpacks on the Salt-Verde River Basin is discussed. However, the anticipated results should also apply to comparable forest, physiographic, and climatic conditions elsewhere in Arizona.

**476. Ffolliott, P.F.; Thorud, D.B. 1977. The Southwest frozen assets: Snowpack management. Western Snow Conference 45:12–18.**

A review of snow research illustrates the possibilities for enhancing snowmelt water yield through vegetative management. Guidelines for managing high elevation, forested watersheds for water-yield improvement and multiple-use values are provided.

**477. Ffolliott, P.F.; Thorud, D.B.; Enz, R.W. 1972. An analysis of yearly differences in snowpack inventory- prediction relationships. Hydrology and Water Resources in Arizona and the Southwest 2:31–42.**

Inventory-prediction relationships developed from long-term Snow Survey records are presented. While the snowpack water equivalent changes as a function of precipitation input, the trade-off between snowpack water equivalent and forest density frequently remains unchanged.

**478. Garn, H.S. 1969. Factors affecting snow accumulation, melt, and runoff on an Arizona watershed. MS Thesis, University of Arizona, Tucson.**

Factors affecting snow accumulation and melt in ponderosa pine forests in north central Arizona are investigated using regression analysis. Sunlight factor, elevation, canopy coverage, and canopy coverage to the north were important variables in predicting snow depth and water content.

**479. Gopen, S.R. 1974. A time-space technique to analyze snowpacks in and adjacent to openings in the forest. MS Thesis, University of Arizona, Tucson, Arizona.**

A mathematical model of snowpack water equivalents related to forest openings is presented. While 2-dimensional in its structure, the model can be extrapolated to 3-dimensions.

**480. Gottfried, G.J.; Ffolliott, P.F. 1981. Evaluation of the use of Soil Conservation Service snow course data in describing local snow condition in Arizona forests. Hydrology and Water Resources in Arizona and the Southwest 11:55–62.**

The Soil Conservation Service (SCS) maintains a system of snow courses to provide an index of snow conditions. Experimental watersheds are located near these snow courses. Comparisons were made between data from the 2 types of snow courses to determine whether the SCS courses adequately represent conditions in surrounding areas.

**481. Hansen, E.A.; Ffolliott, P.F. 1968. Observations of snow accumulation and melt in demonstration cuttings of ponderosa pine in central Arizona. USDA Forest Service, Research Note RM-111.**

A clearcut block on a north aspect and strips with widths of 1 and 1-1/2 times tree height on an east aspect increased snow accumulation, rates of melt, and daily water loss. A strip three-fourths as wide as tree height on a west aspect increased snow accumulation. None of the strips cut on south and southwest aspects affected snowpacks measurably.

**482. Jackson, P.L. 1972. Predicting degree day snow melt factors with crown closure in Arizona ponderosa pine. MS Thesis, University of Arizona, Tucson, Arizona.**

Crown-closure measurements from canopy photographs were related to snow melt through a degree-day model. However, relationships were statistically relatively weak.

**483. Kingdon, L.B. 1987. Harvesting snow in water shy Arizona. Arizona Land and People 37(4):10–15.**

Potentials to augment limited water supplies through management of snowpacks on upland watersheds is discussed. Relevant research is summarized.

**484. Larson, F.R.; Ffolliott, P.F.; Moessner, K.E. 1974. Using aerial measurements of forest overstory and topography to estimate peak snowpack. USDA Forest Service, Research Note RM-267.**

Where slope steepness and aspect vary widely and forest overstory size and density classes are intermixed, only topographic attributes need to be measured. On nearly level sites with homogeneous size and density classes, forest overstory attributes must be measured. All tested photo scales were satisfactory.

**485. Lejcher, T.R. 1969. Snow accumulation and melt under various densities of ponderosa pine in Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

Snow accumulation and melt patterns under several densities of pine in north central Arizona are analyzed using 3 statistical methods. Different stocking levels did not influence snow accumulation, but snow melted more rapidly in stands of low density than in stands of high density.

**486. Nibler, G.J. 1973. The use of upper air data in the estimation of snow melt. MS Thesis, University of Arizona, Tucson, Arizona.**

A snowmelt model was developed using rawinsonde observations of temperature, dewpoint, and wind speed as input variables and the snow-surface energy balance, with the energy budget components structured to accommodate the upper air data. Some physical characteristics of the watershed in north central Arizona were incorporated as parameters of the model.

**487. Solomon, R.M. 1974. An assessment of snowpack depletion-surface runoff relationships on forested watersheds. MS Thesis, University of Arizona, Tucson, Arizona.**

Results of studies into the understanding and prediction of runoff efficiencies from snowmelt in ponderosa pine watersheds in north central Arizona are presented. A technique for determining daily values of runoff efficiencies by coupling a computer model for simulating snowmelt with graphical techniques of runoff hydrograph separation is also outlined.

**488. Solomon, R.M.; Ffolliott, P.F.; Baker, M.B., Jr.; Gottfried, G.J.; Thompson, J.R. 1975. Snowmelt runoff efficiencies on Arizona watersheds. Arizona Agricultural Experiment Station, Research Report 274.**

Efficiencies for several experimental watersheds in different vegetation types are presented. Tentative regression equations were developed relating snowpack runoff efficiencies to inventory-prediction variables. Timing of precipitation during the accumulation-melt period was of prime significance.

**489. Solomon, R.M.; Ffolliott, P.F.; Baker, M.B., Jr.; Thompson, J.R. 1976. Computer simulation of snowmelt. USDA Forest Service, Research Paper RM-174.**

A modification of a previously developed computer model of snowmelt provides for simulating intermittent snowpack conditions and is a more generalized model. Simulated snowmelt depends on 4 daily input variables: maximum and minimum temperatures, precipitation, and shortwave radiation or percent cloud cover.

**490. Solomon, R.M.; Ffolliott, P.F.; Thorud, D.B. 1975. Characterization of snowmelt runoff efficiencies. In: Proceedings, Watershed Management Symposium, ASCE, Irrigation and Drainage Division [Logan, UT., Aug. 11–13, 1975], pp. 306–326.**

Assessment and evaluation of snowmelt runoff efficiencies are described. This information promotes identification of comparative hydrologic potentials and provides insight about watersheds on which forest management practices could be implemented for water-yield improvement.

**491. Thorud, D.B.; Ffolliott, P.F. 1971. Progress in developing forest management guidelines for increasing snowpack water yields. Hydrology and Water Resources in Arizona and the Southwest 1:291–300.**

A research project to develop forest management guidelines for increasing water yields from snowpacks in the ponderosa pine forests on the Salt-Verde River Basins is outlined. A PERT network of the investigative framework for the project is presented to illustrate the study activities involved.

**492. Thorud, D. B.; Ffolliott, P.F. 1972. Development of management guidelines for increasing snowpack water yields from ponderosa pine forests in Arizona. In: National Symposium on Watershed in Transition. American Water Resources Association and Colorado State University, Fort Collins, Colorado, June 19–21, 1971, pp. 171–173.**

Initial work in the development of forest management guidelines for increasing snowpack water yields in the Salt-Verde River Basin is described. These guidelines consider constraints imposed by management objectives involving timber, forage, wildlife, and recreational opportunities.

**493. Thorud, D.B.; Ffolliott, P.F. 1976. Arizona's frozen assets: Snowpack management. Arizona Watershed Symposium Proceedings 19:31–34.**

A review of snow research efforts in the previous 10 years is presented to show the possibilities for enhancing snowmelt water yield. These efforts have been aimed at the development of snow management guidelines to increase the amount of recoverable water from snowpacks on forested watersheds.

**494. Timmer. M.J. 1980. Snowpack dynamics of southwestern aspen forests. MS Thesis, University of Arizona, Tucson, Arizona.**

Snowpack accumulation and melt patterns in aspen stands of differing densities are described. Comparisons are also made with adjacent ponderosa pine stands.

**495. Timmer, M.J.; Ffolliott, P.F.; Baker, M.B., Jr. 1984. Snowpack dynamics in aspen stands near the San Francisco Mountains, Arizona. Hydrology and Water Resources in Arizona and the Southwest 14:51–55.**

Empirical information describing snowpack accumulation and melt in aspen stands is presented and compared to information from adjacent ponderosa pine stands in north central Arizona.

**496. Tunnicliff, B.M. 1975. The historical potential of snowfall as a water resources inn Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

The use of dendrochronologies in describing the historical patterns of snow accumulations on upland watersheds is discussed. A perspective on the role of snow in supply water is also presented.

**497. Welch, B.W. 1975. Validation of snowpack inventory-prediction relationships in Arizona ponderosa pine forests. MS Thesis, University of Arizona, Tucson, Arizona.**

Snowpack inventory-prediction equations are applied to winter conditions on 3 study sites located along the Mogollon Rim in Arizona to validate them as potential management tools. The equations used indicate the trade off potential between water and wood.

## Soils (Physiography)

**498. Aldon, E.F. 1968. Moisture loss and weight of the forest floor under pole-size ponderosa pine stands. Journal of Forestry 66:70–71.**

From 7 to 27% of gross precipitation was lost from the forest floor of pine stands in north central Arizona during a 30-day sampling period in the summer.

**499. Anderson, T.C., Jr.; Williams, J.A.; Crezee, D.B. 1960. Soil management report for Beaver Creek Watershed. USDA Forest Service, Region 3, Coconino National Forest, 66 p.**

Soil survey information obtained on the Beaver Creek Watershed in north central Arizona is presented. Factors mapped are kinds of soils, degree and extent of surface and gully erosion, and other physical factors associated with soils such as rock types, slope, relief, aspect, and vegetative cover.

**500. Blecker, R.F. 1969. Saturated flow of water through clay loam subsoil material of the Brolliar and Springerville soil series. In: Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

Water transmission characteristics of the subsoils of 2 typical Beaver Creek soil series in north central Arizona are presented. Two significant features of these soils are their low permeability of the materials and their departure from proportional flow theory. In the absence of cracks, root, or other channels, only about 8 gallons of water a day would pass through a 3 ft depth per/acre if a 1 cm depth of water were maintained at the surface.

**501. Clary, W.P.; Ffolliott, P.F. 1969. Water holding capacity of ponderosa pine forest floor layers. Journal of Soil and Water Conservation 24:22–23.**

The water holding capacity and total water retention of the forest floor under pine in north central Arizona are presented. Results indicate that if the ability of the forest floor to intercept and hold precipitation is to be reduced, the H layer of the floor must be removed or modified.

**502. Clary, W.P.; Ffolliott, P.F.; Zander, A.D. 1966. Grouping sites by soil management areas and topography. USDA Forest Service, Research Note RM-60.**

Land strata related to herbage production on areas cleared of timber and site index on areas supporting timber are described.

**503. Ffolliott, P.F.; Clary, W.P.; Baker, M.B., Jr. 1976. Characteristics of the forest floor on sandstone and alluvial soils in Arizona's ponderosa pine type. USDA Forest Service, Research Note RM-308.**

Forest floor depths and weights under ponderosa pine stands on soils developed from sedimentary parent materials are presented. These characteristics are largely similar to those reported in soils developed from volcanic parent materials.

**504. Ffolliott, P.F.; Clary, W.P.; Davis, J.R. 1968. Some characteristics of the forest floor under ponderosa pine in Arizona. USDA Forest Service, Research Note RM-127.**

The forest floor affects the hydrologic cycle, herbage production, tree regeneration, and fire behavior. Forest floor depths and weights under pine stands on soils developed from basalt and volcanic cinders are described. Frequency distributions of depths were developed as a management tool when critical ranges of depths affecting wildland products are defined.

**505. Ffolliott, P.F.; Larson, F.R.; Thill, R.E. 1977. Some characteristics of Arizona's mixed conifer forest floor. USDA Forest Service, Research Note RM- 342.**

The forest floor affects the hydrologic cycle, herbage production, tree regeneration, and fire behavior. Forest floor depths and weights under mixed conifer stands on soils developed from basalt and volcanic cinders are described. Frequency distributions of depths were developed as a management tool.

**506. Garn H.S. 1969. The volume-water content relationship of two Beaver Creek soils. In: Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

One of the most hydrologically significant features of the soils in the Beaver Creek area of north central Arizona is their pronounced shrinking and swelling as they are dried and wetted. Some estimates of this phenomena and its probable causes are presented.

**507. Hendricks, D.M. 1979a. Chapter 3, The release of nutrients from parent materials as influenced by weathering. In: Klemmedson, J.O.; Hendricks, D.M. 1979. Study of nutrient and soil balance in ponderosa pine ecosystems in relation to stand composition and land treatment, Report Prepared by University of Arizona, Tucson, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The effects of weathering on nutrients released from parent materials as influenced by stand composition and land treatment are presented. To assess the role that rock weathering may have on the nutrient regime of the pine ecosystem, 2 approaches were made. The first approach concerns the nature, distribution, and nutrient status of the major soils within the ponderosa pine zone. Particular emphasis was placed on soil properties that, directly and indirectly, control or influence the geochemical changes of several important nutrient elements during weathering and soil formation. The second approach was more fundamental. The thermodynamics and kinetics of chemical weathering were studied in laboratory weathering experiments to further understand how elements are released from minerals during the chemical weathering of basalt.

**508. Hendricks, D.M. 1979b. Chapter 6, Soil formation rates as related to forest watershed conditions. In: Klemmedson, J.O.; Hendricks, D.M. 1979. Study of nutrient and soil balance in ponderosa pine ecosystems in relation to stand composition and land treatment, Report Prepared by University of Arizona, Tucson, Arizona,**

**Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The rate of soil formation and relationship of changes in soil formation rates to selected watershed conditions are presented.

**509. Klemmedson, J.O. 1979a. Chapter 2, Nutrient input by precipitation and the effect of precipitation on nutrient transfer by throughfall and stemflow. In: Klemmedson, J.O.; Hendricks, D.M. 1979. Study of nutrient and soil balance in ponderosa pine ecosystems in relation to stand composition and land treatment, Report Prepared by University of Arizona, Tucson, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The annual input of major nutrients into the forest via precipitation and dry fallout are determined. The effect of precipitation on nutrient transfer by throughfall and stemflow are also included.

**510. Klemmedson, J.O. 1979b. Chapter 4, Transfer of nutrients from the standing forest to the forest floor by litterfall. In: Klemmedson, J.O.; Hendricks, D.M. 1979. Study of nutrient and soil balance in ponderosa pine ecosystems in relation to stand composition and land treatment, Report Prepared by University of Arizona, Tucson, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The rate of return of nutrients by litterfall from standing vegetation to the forest floor in various communities of the pine type are presented including those that harvesting treatments have been applied.

**511. Klemmedson, J.O. 1979c. Chapter 5, Decomposition of forest floor and transfer of nutrients to the soil. In: Klemmedson, J.O.; Hendricks, D.M. 1979. Study of nutrient and soil balance in ponderosa pine ecosystems in relation to stand composition and land treatment, Report Prepared by University of Arizona, Tucson, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The rate of return of nutrients from the forest floor to the soil and how this rate is influenced by stand composition, site variables, and harvesting practices are presented.

**512. Klemmedson, J.O. 1981. Chapter 4 (revision), Transfer of nutrients from the standing forest to the forest floor by litterfall. In: Klemmedson, J.O.; Hendricks, D.M. 1979. Study of nutrient and soil balance in ponderosa pine ecosystems in relation to stand composition and land treatment, Report Prepared by University of Arizona, Tucson, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

This is a revision (see 510, Klemmedson 1979b) that includes additional work called for in Objective 2 of Amendment 1 to cooperative Agreement No. 16-821-CA, which was a follow-up research project.

**513. Klemmedson, J.O. 1987. Influence of oak in pine forests of central Arizona on selected nutrients of forest floor and soil. Soil Science Society of America 51:1623–1628.**

The effect of Gambel oak on selected nutrients properties of the ponderosa pine forest floor and underlying soil in north central Arizona are presented.

**514. Klemmedson, J.O.; Hendricks, D.M. 1979. Study of nutrient and soil balance in ponderosa pine ecosystems in relation to stand composition and land treatment. Final Report Prepared by University of Arizona, Tucson, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

The purpose of this study was to examine the movement of nutrients in the pine forest of north central Arizona in relation to ecosystem processes and composition of the forest. Chapter 1 presents the introduction, purpose, design, and location of the studies. There are 6 chapters in this final report (see 478 through 483).

**515. Klemmedson, J.O.; Meier, C.E.; Campbell, R.E. 1985. Needle decomposition and nutrient release in ponderosa pine ecosystems. Forest Science 31:647–660.**

The influence of several forest stand conditions on rate of dry matter loss and net nutrient release from a uniform substrate of decomposing pine needles are presented. Needles declined steadily in mass and without treatment differences for the first 10 months. Differences among treatments began to increase, thereafter.

**516. Klemmedson, J.O.; Meier, C.E.; Campbell, R.E. 1990. Litter fall transfers of dry matter and nutrients in ponderosa pine stands. Canadian Journal of Forest Research 20:1105–1115.**

The effects of stand type on amount, rate, and periodicity of dry matter and nutrient transfer via litter fall are reported for pine stands in north central Arizona.

**517. Lefevre, R.E. 1974. Effects of Gambel oak on the characteristics of litter in a ponderosa pine forest. MS Thesis, University of Arizona, Tucson, Arizona.**

With increased oak density, significant changes in weight, density, and thickness of L, F, and H litter layers in north central Arizona were associated with more rapid decay of oak-dominated litter. Nitrogen and C levels in the forest floor and soil were higher with increased amounts of oak.

**518. Lefevre, R.E.; Klemmedson, J.O. 1980. Effect of Gambel oak on forest floor of a ponderosa pine forest. Soil Science Society of America 44:842–846.**

With increased oak density, significant changes in weight, density, and thickness of L, F, and H litter layers in north central Arizona were associated with more rapid decay of oak-dominated litter. Nitrogen and C levels in the forest floor and soil were higher with increased amounts of oak.

**519. Rector, J.R. 1969a. Infiltration characteristics of soils in the Beaver Creek area of north central Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

Infiltration characteristics of several major soil series in north central Arizona were measured and conform to infiltration theory. Equations of the functional relationships between infiltration and the physical properties of these soils are presented to estimate the maximum capacity of the soils to absorb water.

**520. Rector, J.R. 1969b. Infiltration characteristics of soils in the Beaver Creek area of north central Arizona. In: Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

Equations developed may be used to estimate the probable maximum capacity of the soils to absorb water for antecedent moisture conditions under which the study was made.

**521. Ryan, J.A. 1969a. Sampling study of the physical properties of several soil types in northern Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

Variance of 7 soil physical properties are evaluated within and between watersheds in north central Arizona to determine adequacy of a soil sampling scheme. Variance did not usually increase with watershed size and simple random sampling was just as effective for the majority of measurements as stratification by soil mapping units.

**522. Ryan, J.A. 1969b. Sampling study of the physical properties of several soil types in northern Arizona. In: Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

Important features of the soils studied on Beaver Creek are similarity between soil series, homogeneity of variances between soil series of soil properties measured, and "macrouniformity" phenomena, which is when the variation between adjacent points is greater than that between widely separated points.

**523. Santa Cruz, R.M. 1969. Analysis of soil profile descriptions. In: Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

Analysis of soil physical properties were made of the soil profiles sampled on Beaver Creek in north central Arizona. Subjective differences existed between soil series but from an objective or descriptive point these differences were not clearly defined.

**524. Scholl, D.G. 1971. Soil wettability in Utah juniper stands. Soil Science Society of America Proceedings 35:344–345.**

Wettability varied widely between 3 ground-cover zones and 3 soil horizons in north central Arizona. Resistance to wetting in the surface soil increased from completely wet in open areas to highly non wet in the litter under the tree canopy. Wetting decreased with depth into the soil and increased with increasing organic matter.

**525. Skau. C.M. 1964. Soil water storage under natural and cleared stands of alligator and Utah juniper in northern Arizona. USDA Forest Service Research Note RM-24.**

Investigations of the influence of clearing juniper on soil water storage indicated that considerably more water may be available for forage production but clearing will have little effect on water yield.

**526. Storey, G.E. 1968. A mycological study of some soils of the Arizona pinyon- juniper type. Arizona Forestry Notes No. 3, School of Forestry, Northern Arizona University, Flagstaff, Arizona.**

Population differences of microorganisms exits between 2 major soil series in the pinyon-juniper type in north central Arizona. Differences can be attributed to physical differences in the soils and possibly to inhibiting chemicals produced by the juniper trees.

**527. Story, M.T. 1974. Nitrogen fixation by *Ceanothus fenderi* and *Lupinus argenteus* as a function of parent material and vegetal cover. MS Thesis, University of Arizona, Tucson, Arizona.**

The importance of symbiotic relationships between nitrogen fixing organisms and *Lupinus argenteus* and *Ceanothus fendleri* in ponderosa pine forest in north central Arizona were determined. Information on the ecological role of nitrogen fixing plants and their possible uses in forest and range management are discussed.

**528. Thames, J.L. 1969a. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

This report describes the physical properties and hydrologic characteristics of several soils on the watershed located in north central Arizona and the variation within and between the soil types. A sampling model for soils in the area and methods for characterizing the hydraulic behavior of the soils were developed.

**529. Thames, J.L. 1969b. The size distribution of surface rocks on several Beaver Creek watersheds. In: Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

A means of describing the size distribution of rock cover on soils in north central Arizona are presented. Such information is useful in development of mathematical models of surface runoff, in erosion studies, or to explain possible hydrograph abnormalities.

**530. Thames, J.L. 1969c. A watershed soil sampling guide. In: Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

A slide rule device for estimating the optimum number of soil sample points or subsamples to take for a given precision or for fixed cost for soils in north central Arizona are presented.

**531. Welch, T.G. 1973. Distribution of nitrogen and carbon in ponderosa pine ecosystems as a function of parent material. PhD Dissertation, University of Arizona, Tucson, Arizona.**

Distribution of nitrogen and carbon in soils developed from 4 parent materials and supporting pine vegetation in north central Arizona are discussed.

**532. Williams, J.A. 1969. Soil profile descriptions. In:**

**Thames, J.L. 1969. A study to determine the hydrologic and physical properties of some Beaver Creek soils. Department of Watershed Management, University of Arizona, Tucson, Arizona. 330 p.**

Soil profiles, as described by Forest Service soil scientists, of all pits sampled on 5 watersheds on Beaver Creek in north central Arizona are presented.

**533. Williams, J.A.; Anderson, T.C., Jr. 1967. Soil survey of Beaver Creek area, Arizona. USDA Forest Service, Soil Conservation Service, and Arizona Agriculture Experiment Station.**

This survey contains information that can be applied in managing forests, watersheds, and range; in selecting sites for roads, ponds, buildings, or other structures; and in appraising the value of tracts of land for recreation purposes and as a habitat for wildlife.

## Water Quality

**534. Avery, C.C. 1981. Water quality constrains on the use of recreational impoundment in northern Arizona. Eisenhower Consortium Grant 262.**

Assessment of Ashurst Lake, a small recreational lake in north central Arizona, is presented including a historical review and hydrologic setting of the lake and a physical and chemical description.

**535. Brown, C.C. 1978. Nutrient analysis of precipitation on two sites in northern Arizona. MS Thesis, Northern Arizona University, Flagstaff, Arizona.**

Measurements of atmospheric rainfall deposition, nitrate-nitrogen, total Kjeldahl nitrogen, potassium calcium, sodium, and magnesium were used to determine if input differences of nutrients exist between forested sites with different degrees of disturbance.

**536. Ffolliott, P.F. 1989. Water quality of streamflow from forested southwestern watersheds. In: Preconference Proceedings of the Advances in Management of Southwestern Watersheds. American Water Resources Association, New Mexico Section, Socorro, New Mexico, September 14–15, 1989, p. 4. (Abstract)**

Baseline information on the dissolved chemical constituents of streamflow is presented. This information helps to quantify the hydrologic properties of forested watersheds.

**537. Ffolliott, P.F. 1990. Water quality of streamflow from selected forested watershed in Arizona. Hydrology and Water Resources in Arizona and the Southwest 19:1–5.**

Dissolved chemical constituents of streamflow from the Beaver Creek, Heber, and Thomas Creek watersheds are presented. Comparisons with water quality criteria proposed the Environmental Protection Agency and the Department of Environmental Quality are made.

**538. Ffolliott, P.F. 1993. Acidity of Arizona's snowpacks. Journal of the Arizona-Nevada Academy of Science. Proceedings Supplement 28:48. (Abstract)**

Results of sampling in the winter of 1991 through 1992 showed little evidence of widespread acidity problems. The pH values observed clustered around 5.98, with the normal frequency distribution of these values being similar to those elsewhere in the Western United States.

**539. Ffolliott, P.F. 1994. Concentrations of chemical constituents of Arizona's snowpack and snowmelt streamflow: A comparison. Journal of the Arizona-Nevada Academy of Science, Proceedings Supplement 29. (Abstract)**

Concentrations of selected chemical constituents in snowpacks were lower than those reported in snowmelt streamflow from forested watersheds. The concentrations detected were too low to provide helpful insight into the atmospheric interactions of the constituents.

**540. Ffolliott, P.F.; Lopes, V.L. 1993. Acidity and chemistry of Arizona's snowpacks. In: Allen, R. G., and C. M. U. Neale, editors. Proceedings of the National Conference on Management of Irrigation and Drainage Systems: Integrated perspectives. American Society of Civil Engineers, Park City, Utah, July 21–23, 1993, pp. 305–310.**

Results of sampling of snowpack acidity in the winter of 1991 through 1992 are reported. Concentrations of K, Na, Ca, Mg, F, Cl, NO3, and SO4 were low. No "hot spots" were observed.

**541. Gosz, J.R. 1975. Stream chemistry as a tool in evaluating ski area development. Eisenhower Consortium Bulletin No. 1, Man, Leisure and Wildlands: A complex interaction. First Eisenhower Consortium Research Symposium, Vail, Colorado, pp. 183–194.**

The influence of ski area development is examined in north central New Mexico. The major factor influencing water quality is application of road salt; sewage disposal affected inorganic water quality to a minor degree.

**542. Gosz, J.R.; White, C.S.; Ffolliott, P.F. 1980. Nutrient and heavy metal transport capabilities of sediment. Water Resources Bulletin 16:927–933.**

Geology and vegetation of a watershed are predictors of the nutrient and heavy metal transporting capacity of its suspended sediment. Analyses of acid-digestible and extractable nutrients showed differences for sediments from ponderosa pine forests on different geologies. These differences were similar for soil, streambank, and stream channel material for a site. Different vegetation on a specified geology affected the organic matter content, cation exchange capacity, total P, and levels of extractable nutrients in sediment.

**543. Gregory, P.W. 1976. The water quality of streamflow from ponderosa pine forests on sedimentary soils. MS Thesis, University of Arizona, Tucson, Arizona.**

Baseline chemical, physical, and bacteriological characteristics are presented. Inferences are drawn between water quality of streamflow from watersheds on sedimentary and volcanic soils.

**544. Gregory, P.W.; Ffolliott, P.F. 1976. Water quality of streamflow from forested watersheds on sedimentary soils. Hydrology and Water Resources in Arizona and the Southwest 6:93–95.**

Information is presented on chemical, physical, and bacteriological water quality parameters from ponderosa pine watersheds in north central Arizona. This information is also compared to EPA water quality criteria available.

**545. Johnsen, T.N., Jr. 1980. Picloram in water and soil from a semiarid pinyon- juniper watershed. Journal of Environmental Quality 9:601–605.**

An herbicide was applied to the study area in north central Arizona and residues in runoff and soil were monitored. A total of 1.1% of the picloram applied left the area in runoff. The herbicide was detected in the soils for 44 months after application; mainly below 45-cm.

**546. Klemmedson, J.O.; Meier, C.E.; Campbell, R.E.; Marx, D.B. 1983. Effect of stand composition and season on chemistry of throughfall and streamflow of ponderosa pine forests. Forest Science 29:871–887.**

Results of the influence of forest stand conditions on input and cycling of 7 major nutrients by precipitation, throughfall, and stemflow in north central Arizona are presented. Patterns for amount of nutrients transferred was strongly seasonal with the largest amount delivered in midsummer.

**547. Oakley, S.M.; Segal, B.A.; Johnson, R.M. 1977. Chemical and microbiological characteristics of two recreation oriented, oligotrophic mountain lakes. Journal of Arizona Academy of Science 12:36–46.**

Microbiological and chemical limnological properties that characterize relatively pristine or oligotrophic lakes are identified to facilitate detection of water quality change before gross pollution occurs.

**548. Tecle, A. 1991. Chapter 6. Water quality in southwestern ponderosa pine forests. In: Tecle, A. and W.W. Covington, Technical editors. 1991. Multiresource management of southwestern ponderosa pine forests: The status of knowledge. USDA Forest Service, Southwestern Region Report, pp. 273–314.**

A review of the current knowledge of water quality in pine forest is presented. An examination of possible future impacts of vegetation management on the quality of water is also included. Erosion and sediment yield are discussed in detail since they are widely recognized as the major water quality problem in the area. Other chemical, biological, and physical water quality problems in the forest system are also reviewed.

**549. US Environmental Protection Agency. 1977. Nonpoint water quality modeling in wildland management: A state-of-the-art assessment. USDA Forest Service, Interagency Agreement No. EPA-1AG-D5-0660, Ecological Research Series No. EPA-600/3-77-036 Washington, D.C.**

The main objective of this report was to define the relationship between wildland management practices and non-point sources of pollution. A discussion of prediction techniques related to forest management activities and an inventory of monitored watersheds having data suitable for model development and testing is included. J.J. Rogers and D.R. Carder, scientists on the Beaver Creek Project, participated in assembling the information in this document.

## Water-yield Improvement

**550. Affleck, R.S. 1975. Potential for water yield improvement in Arizona through riparian vegetation management. PhD Dissertation, University of Arizona, Tucson, Arizona.**

A comprehensive review of potential multiple-use management is presented. The role of riparian communities in watershed management is stressed.

**551. Arizona Water Resources Committee. 1965. The Arizona watershed program of the United States Department of Agriculture, Forest Service. Arizona Water Resources Committee, Phoenix, Arizona.**

Water is the most vital resource of watersheds in Arizona. The results of this program will determine future management practices, which must consider the needs and relative importance of all watershed resources and uses.

**552. Arizona Water Resources Committee. 1974. More water for Arizona. Arizona Water Resources Committee, Phoenix, Arizona.**

Potentials for water-yield improvement through vegetative management practices on Arizona's upland watersheds are presented. Estimates of contributions from the vegetative types are also made.

**553. Baker, M.B., Jr. 1982. Changes in streamflow in an herbicide-treated pinyon- juniper watershed in Arizona. Hydrology and Water Resources in Arizona and the Southwest 12:19–25.**

Results of the 8-year period following the application of herbicides on water yield are documented.

**554. Baker, M.B., Jr. 1983. Influence of slash windrows on streamflow. Hydrology and Water Resources in Arizona and the Southwest 13:21–25.**

Removal of slash windrows has apparently caused some reduction in annual water yield response from a cleared ponderosa pine watershed in north central Arizona.

**555. Baker, M.B., Jr. 1984. Changes in streamflow in an herbicide-treated pinyon- juniper watershed in Arizona. Water Resources Research 20:1639–1642.**

The herbicide treatment induced an increase in annual streamflow of about 157%. There is an indication that after the dead trees were removed, streamflow was reduced to near-pretreatment levels.

**556. Baker, M.B., Jr. 1986a. Effects of ponderosa pine treatments on water yield in Arizona. Water Resources Research 22: 67–73.**

Annual water yields were determined for a combination of 3 levels of overstory removal and thinning applied on pine watersheds. Water yield increases from a completely cleared watershed were significant for 7 years, only losing significance after recovery and growth of Gambel oak and herbaceous vegetation. The longest response in water yield (10 years) was from a heavily thinned watershed and was attributed to the inherent runoff efficiency of the basin.

**557. Baker, M.B., Jr. 1986b. Water yield from treatment of ponderosa pine. In: 30th Annual Arizona Water Symposium Proceedings 30:27–38.**

A resume of Water Resources Research (22:67–73) paper by M.B.Baker, Jr. is presented (see above). The effects of ponderosa pine treatments on water yield in Arizona are considered.

**558. Baker, M.B., Jr. 1988. Selection of silvicultural systems for water. In: Baumgartner, D.M., and J.E. Lotan, editors. Ponderosa pine: The species and its management. Symposium proceedings, Spokane, Washington, September 29–October 1, pp. 201–211.**

Water yields from the ponderosa pine type in the United States average from 3 to 5 inches per year. Opportunities to increase yields exist, but because of its situation in lower elevations and precipitation zones, the potential is not as great as it is in the higher subalpine zone.

**559. Brown, H.E. 1970. Status of pilot watershed studies in Arizona. American Society of Civil Engineers, Journal of Irrigation and Drainage Division 96(IR1):11–23.**

Hydrologic research is reviewed and shows how results are being tested on small watersheds before being applied on a broad management scale. Results have application to the Southwestern United States.

**560. Brown, T.C.; Fogel, M.M. 1987. Use of streamflow increases from vegetation management in the Verde River Basin. Water Resources Bulletin 23:1149–1160.**

Proportion of increased water yields from upland watersheds that reach downstream reservoirs are estimated through simulation techniques. Ownership of increased water is also discussed.

**561. Ffolliott, P.F. 1974a. Potentials for water yield improvement by vegetation management in Arizona. Arizona Watershed Symposium Proceedings 18:47–51.**

Estimates of potential water-yield improvement by vegetative management in operational programs are presented in 2 evaluation levels. First, research information is extrapolated from experimental watershed studies to predict water yield increases from vegetative management practices. Second, areas appearing to have increased water yield potential, as constrained when possible and if appropriate by vegetation, physiography, climate, and social, institutional, and economic factors are determined.

**562. Ffolliott, P.F. 1974b. Water yield improvement opportunities on Arizona's grassland and desert shrub ranges. Arizona Watershed Symposium Proceedings 18:37–39.**

Consideration should be given to the grassland and desert shrub vegetative zones to provide a complete assessment of the opportunities for water-yield improvement by vegetative management. Although the water yielding characteristics are relatively low in these zones, their inclusion in water resources planning might be necessary because of their large coverage in the state.

**563. Ffolliott, P.F. 1985. Vegetation management and water yields—possibilities and limitations. In: Kaul, O.N., S.P. Banerjee, and A.C. Gupta, editors. Proceedings of National Seminar on Watershed Management. National Institute of Hydrology, New Forest, Dehradun, India, pp. 43–49.**

Studies from Switzerland, Japan, Kenya, South Africa, Chile, Australia, and the Southwestern United States are reviewed. Significant results obtained from the Arizona Watershed Program are highlighted.

**564. Ffolliott, P.F.; Brooks, K.N. 1988. Opportunities for enhancing water yield, quality, and distribution in the Mountain West. In: Schmidt, W.C., compiler. Proceedings—future forests of the Mountain West. USDA Forest Service, General Technical Report INT-243, pp. 55–60.**

The existing knowledge relating to these important hydrologic topics is highlighted. Increases in high quality water are possible from many forest types. The magnitude and duration of the water yield increases vary with species compositions, stand structure, and management prescriptions.

**565. Ffolliott, P. F.; Fogel, M.M. 1986. Evaluation of water yield improvement programs: A methodology. First Water Resources Research Conference, Water Resources Research Center, University of Arizona, Tucson, Arizona, p. 1. (Abstract)**

The evaluation method presented requires a delineation of watersheds and net treatable areas, prescription of treatments and their implementation in time and space, calculation of unit and total volumes of increased streamflows resulting from the treatments, development of a time series to determine frequencies of increased flows, and optimum allocation of resources.

**566. Ffolliott, P.F.; Fogel, M.M. 1987. Potential for increasing water yields to active management areas through vegetation management. Arizona Water Symposium 30:73–79.**

Alternative models of water-yield improvement are presented. A generalized procedure for determining the capability of a watershed for augmenting water yields is proposed.

**567. Ffolliott, P.F.; Lopes, V.L. 1993. Opportunities for water yield improvement in dryland regions: A review of catchment experiments. In: Castillo, G.J., M. Tiscareno L., and I. Sanchez C., editors. Proceedings of the First International Seminar of Watershed Management. University of Sonora, Hermosillo, Mexico, pp. 24–29.**

An overview of worldwide process studies and catchment experiments is presented. Findings of the Arizona Watershed Program are included.

**568. Ffolliott, P.F.; Thorud, D.B. 1974. Vegetation management for increased water yield in Arizona. Arizona Agricultural Experiment Station, Technical Bulletin 215.**

Potentials for increasing water yields from watersheds is presented by vegetative types. These potentials represent gross estimates to be modified through consideration of other natural resources and values. The study was essentially a review of documents published from 1956 through 1974.

**569. Ffolliott, P.F.; Thorud, D.B. 1975a. Vegetation management for water and range management. In: Proceedings, Watershed Management Symposium, ASCE Irrigation and Drainage Division Logan, Utah, pp. 249–266.**

An overview of water-yield improvement research in Arizona is presented in the context of water and range management. Seven vegetative types are considered in a multiple-use framework.

**570. Ffolliott, P.F.; Thorud, D.B. 1975b. Water yield improvement by vegetation management focus in Arizona. U.S. Department of Commerce, National Technical Information Service PB-246 056.**

Separate summaries of research on the potentials for increasing water yields by vegetative management are presented for alpine, mixed conifer, aspen, ponderosa pine, pinyon-juniper, chaparral, grassland, desert shrub, and riparian types. Some of the characteristics covered for each vegetative type include silviculture, plant growth, overstory species composition, climate, hydrology, physiography, recreation, and wildlife and fisheries. The effect of the treatment water yield and quality, timber, and forage are also discussed.

**571. Ffolliott, P.F.; Thorud, D.B. 1976. Water yield improvement: State-of-the-art. In: Proceedings of the Earth Science Symposium. USDA Forest Service, Region Five, Fresno, California, pp. 1–12.**

A review of water-yield improvement experiments is presented to identify the vegetative zones in which water yield has potential and to describe the vegetative practices that have increased water yield. While the information generated from these experiments is applicable only to Arizona, the concepts have application elsewhere.

**572. Ffolliott, P.F.; Thorud, D.B. 1977. Water yield improvement by vegetation management. Water Resources Bulletin 13:563–571.**

An overview of water-yield improvement experiments is presented to identify the vegetative zones in which water yield has potential and to describe the vegetative practices that have increased water yield. Constraints to treatment implementation must be considered to determine treatable areas.

**573. Ffolliott, P.F.; Thorud, D.B. 1984. Water yield by vegetation management in the southwestern United States. In: Proceedings of the Eighth World Forestry Congress, Forestry for Food, Jakarta, Indonesia, October 16–28, 1978, 3:299–308.**

An assessment of water-yield improvement opportunities indicates that modification of the structure and composition of watershed vegetation can increase streamflow runoff. Evidence also suggests that treatments that improve water yield can be compatible with and sometimes complimentary to other natural resources.

**574. Ffolliott, P.F.; Fogel, M.M.; Sikka, A. 1988. Impacts of upstream vegetative management on water yield. In: Proceedings of Seminar on Environmental Considerations in Planning of Water Resources Projects. National Institute of Hydrology, Roorkee, U.P., India, pp. III-9–III-19.**

Concepts of upstream vegetative management for water-yield improvement are presented. Brief summaries of worldwide studies, including those in the Arizona Water Program, are also discussed.

**575. Hassell, M.J. 1976. Forest Service's role in Arizona's water future. Arizona Watershed Symposium Proceedings 20:40–42.**

The role of the USDA Forest Service in studying and developing Arizona's water resource is reviewed, and its future involvement is discussed.

**576. Hibbert, A.R. 1979. Managing vegetation to increase flow in the Colorado River Basin. USDA Forest Service, General Technical Report RM-66.**

Water yield from forest and rangelands is augmented by managing vegetation and snow to reduce evapotranspiration. Some arbitrary goals to increase water yield were chosen to illustrate the potential for increasing water yield. Potentials for the ponderosa pine and pinyon-juniper woodland types were taken from results obtained on Beaver Creek in north central Arizona.

**577. Hurst, W.D. 1974. The application of water yield research to the National Forests of the southwest. Arizona Watershed Symposium Proceedings 18:43–46.**

Results of potential water yields in the report Vegetative Management for Water Yield in Arizona are believed too optimistic because each type is treated as a homogenous complex and multiple-use constraints have not been woven into the prediction calculation.

**578. Price, R. 1967. Possibilities of increasing streamflow from forest and range watersheds by manipulating the vegetative cover—the Beaver Creek Pilot Watershed Evaluation Study. In: Proceedings of the International Union of Forestry Research Organization XIV. IUFRO-Congress, Vol. I, Section 01-02-11, pp. 487–504.**

The potential of increasing water supplies from upstream watersheds through manipulation of vegetative cover in north central Arizona is discussed. When evaluating such projects, the affects on other values and land uses, such as timber, forage, wildlife habitat, and recreational opportunities, must be considered.

**579. Reynolds, H.G. 1961. Vegetation management for water yield in the Southwest. New Mexico Water Conference Proceedings 5:21–33.**

This paper analyzes some of the principles of vegetation management in relation to water yields and some of the possibilities for favoring water yields on watersheds in Arizona and New Mexico.

## Watershed Management

**580. Aldon, E.F. 1960. Research in the ponderosa pine type. In: Watershed management research in Arizona, progress report, 1959. USDA Forest Service, pp. 17–24.**

Basic field data on canopy interception, weight of the forest floor, and moisture content of the forest floor are presented for 3 pole-sized pine areas in Arizona. Streamflow periods and sediment measurements taken on Beaver Creek are also presented.

**581. Arizona State Land Department and the Arizona Water Resources Committee. 1965. The Arizona watershed program (brochure).**

Examples of projects being conducted under the watershed program are explained.

**582. Brooks, K.N.; Ffolliott, P.F.; Thames, J.L. 1983. Principles and concepts of watershed management. In: Proceedings of a National Symposium on Soil and Water Conservation, Bangkok, Thailand, June 23–27, 1982, pp. 226– 234. (Thai)**

The principles and concepts of watershed management are presented. Watershed problems in tropical forest areas, steep and mountainous lands, and drylands throughout the world, including central Arizona, are discussed.

**583. Brown, H.E. 1971. Evaluating watershed management alternatives. American Society of Civil Engineers, Journal of Irrigation and Drainage Division 97(IR1): 93–100.**

Multiple-use results of watershed treatments on the Beaver Creek Pilot Project are summarized, and plans for economic evaluations are briefly outlined.

**584. Carder, D.R. 1976. Woods Canyon: A large scale watershed management experiment: An explanation and interim report. Arizona Watershed Symposium Proceedings 19:43–46.**

Wood Canyon could become more of a demonstration of methods for improving multiple-use planning and management than for improving water yields. Improved models will be used to predict yield changes after various treatment alternatives. Existing gaging stations and other field measurements will show accuracy of model predictions.

**585. Carder, D.R. 1977. Multiresource management research in the Southwest— The Beaver Creek Program. Journal of Forestry 75:582–584.**

Conversion of pinyon-juniper to grass will increase livestock forage but will increase streamflow only if trees are killed with herbicides and left in place. Thinning dense stands of ponderosa pine increases yields of water, forage, and wood. Research has recently been expanded to provide decision-making procedures helpful in multi resource management.

**586. Ffolliott, P.F. 1980. UNESCO's Man and the Biosphere Program: Interdisciplinary and international collaboration on environmental research in temperate forests. In: Abstracts of papers. The 140th National Meeting of the American Association for the Advancement of Science, San Francisco, California, AAAS Publication 80-2, p. 33. (Abstract)**

MAB Project 2 is concerned internationally with the study of ecological and socioeconomic effects of alternative uses and managerial practices in temperate, Mediterranean, and boreal forests. The directorate in the United States has identified specific areas of interdisciplinary collaboration including environmental impacts of wildfire and fuel management policies, effects of forests on energy development, and accumulation, analysis, and transfer of information about forest.

**587. Ffolliott, P.F. 1981. Integrated upland watershed management in the southwestern United States. Journal of Indian Association of Hydrologists 5:8–13.**

Management of vegetation on upland watersheds can increase water yield while benefitting other natural resources. The results of experiments in the Southwestern United States are described for 7 vegetative zones including the ponderosa pine type on Beaver Creek are included.

**588. Ffolliott, P.F. 1985a. Multiple use implications of watershed management. In: Easter, K.W., and M.M. Hufschmidt, eds. Integrated watershed management research for developing countries: Workshop report. Environment and Policy Institute, East-West Center, Honolulu, Hawaii, pp. 26–27. (Abstract)**

Basic objectives and problems with the application of multiple-use management are discussed. Reference to issues in the Southwestern United States is made.

**589. Ffolliott, P.F. 1995b. The Salt River Project: A case study of river basin development and management in the United States. In: Papers for the Seminar on Chiangjiang Water and Soil Conservation and Environmental Protection, Beijing Forestry University, Beijing, China, pp. 94–60. (Chinese)**

The role of the Arizona Watershed Program is discussed within the framework of the project. Evaluations of vegetative management practices show that water yields can often be increased in a multiple-use framework.

**590. Ffolliott, P.F.; Brooks, K.N. 1985a. Current research trends in watershed management in the United States and several other countries. In: Kaul, O.N., S.P. Banerjee, and A.C. Gupta, eds. Proceedings of National Seminar on Watershed Management. National Institute of Hydrology, New Forest, Dehradun, India, pp. 217–223.**

Examples of watershed research show the importance placed on land and water management. Results from work on the Beaver Creek watershed are presented.

**591. Garrett, L.D.; Covington, W.W.; Tecle, A. 1989. Research needs in the Southwest ponderosa pine type. In: Tecle, A., W.W. Covington, and R.H. Hamre, Technical Coordinators. 1989. Multiresource management of ponderosa pine forests. USDA Forest Service, General Technical Report RM-185. pp. 6–13.**

Research needs for the ponderosa pine/Arizona fescue ecotype of Arizona and the greater Southwest are discussed relative to trends in national and regional forest resource demands. Critical resource demands in the Southwest will involve water, recreation, wildlife, and timber.

**592. Kennedy, F.H. 1959. National Forest watershed projects in Arizona. Arizona Watershed Symposium Proceedings 3:51–62.**

Pilot tests and research projects are being designed to develop methods of optimum forest land management with coordination of uses. Accomplishments obtained during the first 3 years of the projects are included.

**593. Lloyd, R.D. 1966. Beaver Creek pilot watershed evaluation project. USDA Forest Service, Miscellaneous Report.**

This paper describes the first and only organized effort designed to measure and determine what humans can do to increase water yield from national forest land and to analyze the results in terms of all forest land values.

**594. Piatt, J.R.; Krause, P.D. 1974. Road and site characteristics that influence road salt distribution and damage to roadside Aspen trees. Water, Air, and Soil Pollution 3:301–304.**

Extensive necrosis of aspen leaves appeared on downhill side of a paved road in New Mexico. Chloride concentrations in leaf tissues were significantly correlated with leaf damage.

**595. Price, R. 1958. Watershed management research in the Southwest (A literature review). In: American Forestry Association's 83rd Annual Meeting, October 27–30, Tucson, Arizona.**

The Southwest, as defined here, includes Arizona, New Mexico, and adjacent areas in Texas, Colorado, Utah, and California. Some research completed elsewhere that bears on the water problem in the Southwest is also included. The scope is limited mostly to pertinent findings that are published and readily available.

**596. Price, R. 1976. History of Forest Service Research in the Central and southern Rocky Mountain Regions, 1908–1975. USDA Forest Service General Technical Report RM-27.**

History of Forest Service research in the region is discussed from the first established at Fort Valley Experimental Forest near Flagstaff. The Arizona Watershed Program is discussed, which included the work on the Beaver Creek Watershed.

**597. Price, R.; Hoover, M.D. 1957. Watershed management research in Arizona conducted by the Forest Service. Arizona Watershed Symposium Proceedings 1:5–10.**

Describes watershed management research by the Rocky Mountain Forest and Range Experiment Station in various vegetation types in Arizona, which includes work in the pinyon-juniper and ponderosa pine types on Beaver Creek.

**598. Reynolds, H.G. 1960a. Current watershed management research by the U.S. Forest Service in Arizona. Arizona Watershed Symposium Proceedings 3:63–93.**

Summaries of watershed management research currently being conducted in Arizona are reported. Initial work in the pinyon-juniper and ponderosa pine type on Beaver Creek are included.

**599. Reynolds, H.G. 1960b. Scope of current watershed management research in Arizona. In: Watershed management research in Arizona, progress report, 1959, pp. 1–4.**

General characteristics and locations of the 5 major vegetational types and experimental areas for watershed management research in Arizona are outlined by maps and tabulations.

**600. Reynolds, H.G. 1960c. Watershed management research in Arizona and New Mexico. Journal of Forestry 58:275–278.**

Research by the Forest Service in Arizona and New Mexico is emphasizing water yields at the higher elevations, coordinating watershed with timber and range management at intermediate elevations, and reducing flood flow and sedimentation at the lower elevations is reported. More intensive watershed management practices should result in more water, timber, livestock grazing, game, and recreation for an expanding population.

**601. Skau, C.M. 1960. Watershed management research in the pinyon-juniper type. In: Watershed management research in Arizona, progress report, 1959, pp. 25–29.**

This paper summarizes the relationship of interception and surface runoff to 3 stand-density classes of pinyon-juniper.

**602. Thorud, D.B.; Ffolliott, P.F. 1972. Development of management guidelines for increasing snowpack water yields from ponderosa pine forests in Arizona. In: National symposium on watershed in transition. American Water Resources Association and Colorado State University, Fort Collins, Colorado, June 19–21, 1971, pp. 171–173.**

Operational forest management guidelines to increase water yields from snowpacks in ponderosa pine are presented. These guidelines should apply to comparable forest, physiographic, and climatic conditions in Arizona and may be applicable to forest regions outside the state.

**603. USDA Forest Service. 1977a. The Beaver Creek Program. Advancing forest and range resource management. USDA Forest Service, Brochure—English and Spanish Version.**

The program of watershed management research in the Beaver Creek area of the Coconino National Forest in north central Arizona is described.

**604. USDA Forest Service. 1977b. Application for designation of the Beaver Creek Watershed as a Biosphere Reserve. Project 8 Man and the Biosphere Program UNESCO. p. 25.**

The purpose of the Beaver Creek Watershed as a Biosphere Reserve is to provide a large watershed on which intensive environmental and economic data has been gathered. This area offers the opportunity for monitoring and evaluating a broad spectrum of natural and human effects of ongoing Forest Service management and related activities, and then communicating the findings of the studies to people involved or interested in natural resource planning and management.

**605. Wilm, H.G. 1967. The Arizona watershed program as it enters into its second decade. Arizona Watershed Symposium Proceedings 10:9–11.**

After 10 years, the Barr Report is reevaluated and the results from the Arizona Watershed Program are compared with those of the original proposal.

## Wildlife Resources

**606. Balda, R.P. 1975. Vegetation structure and breeding bird diversity. In: Smith, D. R., technical coordinator. Proceedings of Symposium on Management of Forest and Range Habitats for Nongame Birds. Tucson, Arizona. USDA Forest Service, General Technical Report WO-1, pp. 59–80.**

Relationships between breeding bird diversity and vegetation structure are examined. Foliage height diversity appears to be the most important factor but percent cover, foliage volume, and plant species diversity are also useful measures.

**607. Clary, W.P. 1972. A treatment prescription for improving big game habitat in ponderosa pine forests. Arizona Watershed Symposium Proceedings 16:25–28.**

Treatments are designed to determine the possible differences in wildlife responses to openings in managed and unmanaged forests. One-fifth of the managed timber area will be in permanent openings of 1 to 10 acres; one-third of unmanaged forest will be in such openings.

**608. Clary, W.P. 1990. Overview of ponderosa pine-bunchgrass ecology and wildlife enhancement with emphasis on southwestern United States. In: Fisser, H.G., editor. Proceedings of the sixteenth Wyoming Shrub Ecology Workshop, May 26–27, 1987, Sundance, Wyoming. Laramie, Wyoming: Division of Range Management and University of Wyoming, pp. 11–21.**

Guidelines for maintaining or improving habitats have been developed for many individual wildlife species, but actions that benefit 1 species may cause damage to habitat conditions for other species. Generally, the very early and very late pine forest successional stages are most beneficial for wildlife. Guidelines for Southwestern logging treatments were generally successful as measured by wildlife response.

**609. Clary, W.P.; Larson, F.R. 1971. Elk and deer use are related to food sources in Arizona ponderosa pine. USDA Forest Service, Research Note RM-202.**

Herbage production associated with alligator juniper and ponderosa pine overstories is discussed.

**610. Costa, R. 1976. Cottontail (*Sylvilagus auduboni*) response to ponderosa pine management. MS Thesis, University of Arizona, Tucson.**

The effects of silvicultural treatments on cottontail populations is reported. Clearcutting and windrowing of slash provided the necessary food and cover to increase cottontail numbers.

**611. Costa, R.; Ffolliott, P.F.; Patton, D.R. 1976. Cottontail response to forest management in southwestern ponderosa pine. USDA Forest Service, Research Note RM-330.**

Cottontail populations increased only in a clearcut area where ponderosa pine regeneration provided sufficient food and cover. Windrowing slash and encouraging dense tree regeneration or shrubby and herbaceous undergrowth should improve cottontail habitat under shelterwood and group selection systems.

**612. Cunningham, J.B.; Balda, R.P.; Gaud, W.S. 1980. Selection and use of snags by secondary cavity-nesting birds of the ponderosa pine forest. USDA Forest Service Research Paper RM-222.**

One factor limiting the population size of cavity-nesting birds in ponderosa pine is the number of suitable nesting cavities. A study of snags in north central Arizona showed that pine forests provide a large number of species with nesting and roosting sites. Maintaining cavity nesters at natural population levels requires a density of 5.2 snags /ha in mature pine stands.

**613. Ezcurra, E.; Gallina, S.; Ffolliott, P.F. 1980. Manejo combinado del venado y el ganado en el norte de Mexico. Rangelands 2:208–209. (Spanish)**

Little dietary overlap between deer and cattle exist in the dry, temperate, pine-oak forests on the Biosphere Reserve of La Michilia in northern Mexico. Furthermore, these animals have different preferences for grasses, forbs, and shrubs. Increases in deer populations on areas similar to La Michilia should have little or no effect on the availability of forage for cattle.

**614. Ffolliott, P.F. 1976. An assessment of abert squirrel and cottontail activities on Beaver Creek Watersheds. Final Report Prepared by University of Arizona, Tucson, Arizona, Submitted to the Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.**

Responses of squirrel and cottontail to specific land-management practices under evaluation on the Beaver Creek watersheds are presented. Knowledge of cottontail activities in ponderosa pine forests in the Southwest is essentially non-existent, although use of the adjacent pinyon-juniper woodlands has been described. Relative habitat use of Abert squirrels and cottontail are determined, and information about how and to what degree squirrel and cottontail habitat is affected by land-management practices are indicated.

**615. Ffolliott, P.F. 1981. Integrating deer management with the multiple use concept. In: Ffolliott, P.F., and S. Gallina, eds. Deer biology, habitat requirements, and management in western North America. Instituto de Ecologia, A. C., Mexico, D. F., Publication 9, pp. 181–192.**

Wildlife managers must be aware of the associated multiple-use management potential to effectively practice deer management or, more generally, wildlife management of any species. The problems of integrating deer management into multiple-use management practices are discussed.

**616. Ffolliott, P.F. 1990. Small game habitat use in southwestern ponderosa pine forests. In: Krausman, P., and N.S. Smith, eds. Managing wildlife in the southwest: Proceedings of the symposium, Tucson, Arizona, October 16–18, 1990, Arizona Chapter, The Wildlife Society, Phoenix, Arizona, pp. 107–117.**

A long-term study of Abert squirrel and cottontail habitat use is described. Management implications suggest a variety of forest management practices for maintaining or enhancing habitats for big and small game species.

**617. Ffolliott, P.F.; Clary, W.P.; Larson, F.R. 1976. Observations of beaver activity in an extreme environment. The Southwestern Naturalist 21:131–133.**

Beaver were observed near small, perennial pools that formed in usually dry drainages that dissect desert scrub and riparian hardwood vegetation types on Dry Beaver drainage in north central Arizona.

**618. Ffolliott, P.F.; Patton, D.R. 1975. Production-rating functions for Abert squirrels in southwestern ponderosa pine. Wildlife Society Bulletin, 3:162–165.**

Functions for Abert squirrel food and nest trees, and for pine-tree volume were plotted against each other to form decision-making models for identifying use conflicts. The graphs show competitive stages where the value of one improves while the other declines.

**619. Ffolliott, P.F.; Patton, D.R. 1978. Abert squirrel use of ponderosa pine as feed trees. USDA Forest Service, Research Note RM-362, 4 p.**

Twigs under pine trees were counted to determine Abert squirrel feed-tree patterns and preferences on 5 Arizona watersheds. No pattern of feed-tree selection was found; squirrels preferred trees 14 to 22 inches in diameter, located in sites having 100 to 150 $ft^2$ of basal area/acre. Silvicultural treatments had little effect on feed-tree selection.

**620. Ffolliott, P.F.; Thill, R.E.; Clary, W.P.; Larson, F.R. 1977. Animal use of ponderosa pine forest openings. Journal of Wildlife Management 41:782–784.**

Time-lapse photography indicated elk and cattle preferred openings where slash was piled and burned, rather than piled and left. Deer preferences were similar but not as strong. Turkeys preferred openings where slash was piled and left. Deer and elk moved freely through the center of 3.5–ha openings.

**621. Gallina, S.; Ezcurra, E. 1981. Wildlife management: White-tailed deer in La Michila Biosphere Reserve. In: Ffolliott, P.F., and G. Halffter, technical coordinators. Social and environmental consequences of natural resources policies, with special emphasis on biosphere reserves. USDA Forest Service, General Technical Report RM-88, pp. 26–28.**

White-tailed deer population behavior on the biosphere reserve is described. A general mathematical model to predict population changes and, as a consequence, devise better management practices is also presented.

**622. Goodwin, J.G. 1975. Population densities and food selection of small rodents in Arizona ponderosa pine forests. MS Thesis, University of Arizona, Tucson, Arizona.**

The effects of silvicultural treatments on small rodent populations are discussed. Clearcutting and other treatments consisting of significant modifications in overstory conditions had the greatest impacts on population densities and availability of preferred foods.

**623. Goodwin, J.G.; Hungerford, C.R. 1979. Rodent population densities and food habitats in Arizona ponderosa pine forests. USDA Forest Service, Research Paper RM-214.**

Habitat preference, effect of timber harvesting on population densities, and food habits were determined for small rodents inhabiting ponderosa pine forests in north central Arizona. *Peromyscus maniculatus* was the major species, with a density of 1 to 11/acre. Forbs were the primary summer food for all rodent species. Seeds and flowers comprised 75% of the vegetative diet, and leaves and stems 25%. Approximately 85% of the total diet was vegetation and 15% was insects.

**624. Hungerford, C.R.; Burke, M.D.; Ffolliott, P.F. 1981. Biology and population dynamics of mule deer in southwestern United States. In: Ffolliott, P.F., and S. Gallina, eds. Deer biology, habitat requirements, and management in western North America. Instituto de Ecologia, A. C., Mexico, D. F., Publication 9, pp. 109–132.**

Basic information necessary to manage mule deer is presented. A mathematical model, based largely on energy transfer knowledge, of mule deer population dynamics is also described.

**625. Kruse, W.H. 1972. Effects of wildfire on elk and deer use of a ponderosa pine forest. USDA Forest Service, Research Note RM-226.**

Elk use shifted from an old seeded clearcut to a newly seeded burn for the first 2 years after burning. Elk use of the 2 habitats was equal in the third year. Decreasing deer use on thinned areas continued, but use increased substantially on the wildfire area.

**626. Kruse, W.H.; Balda, R.P.; Simon, M.J.; Macrander, A.M.; Johnson, C.D. 1979. Community development in two adjacent pinyon-juniper eradication areas twenty-five years after treatment. Journal of Environmental Management 8:237–247.**

As a range improvement project, 26-year-old pinyon-juniper trees in north central Arizona were bulldozed to release forage and grasses. Most tests showed that a transmission line corridor in the same habitat was generally different from the native woodland, while the range improvement area was not significantly different from either the corridor or the native condition. This suggests that the range improvement area was in an intermediate stage of development. Bird and mammal populations appeared to develop and change with the vegetation changes, leading to a climax pinyon-juniper woodland.

**627. Larson, F.R.; Ffolliott, P.F.; Clary, W.P. 1986. Managing wildlife habitat—in southwestern ponderosa pine forests, diverse treatments are the key. Journal of Forestry 84(3):40–41.**

University and government researchers cooperated on studies of 6 pine watersheds in Arizona. Changes in wildlife habitat resulting from removing various proportions of the pine overstory were determined. Guidelines were developed to enhance wildlife habitat while managing stands to meet silviculture, range, or other objectives.

**628. McCulloch, C.Y. 1962. Watershed and game management. Arizona Watershed Symposium Proceedings 6:25–27.**

Initial results of investigations by the Arizona Game and Fish Department on the effects of watershed treatments on big game, particularly deer, are presented. Although initial changes in vegetation were obvious, long term changes from ecological succession and continuing vegetation control efforts may have significantly influenced the wildlife species.

**629. McCulloch, C.Y. 1978. Statewide deer food preferences. Arizona Game and Fish Department, Completion Report, Arizona Federal Aid Project W-78-R; WP4, J15, Phoenix, Arizona.**

Summaries of unpublished Arizona deer rumen data collected from 1925 to 1967 are presented. In 1959 and 1960, in woodlands on Beaver Creek, browse was mostly juniper and clubflower, which is a species sometimes abundant but perhaps not much used by deer on other ranges.

**630. Neff, D.J. 1968. Habitat manipulation on pine and juniper watersheds. Arizona Game and Fish Department, Completion Report, Arizona Federal Aid Project W-78-R-12; WP4, J14, Phoenix, Arizona.**

Estimates of deer and elk population densities on ponderosa pine forest and pinyon-juniper woodland watersheds are presented. Effects of pinyon-juniper woodland conversion treatments are summarized.

**631. Neff, D.J. 1972. Responses of deer and elk to Beaver Creek watershed treatments. Arizona Watershed Symposium 16:18–24.**

As indicated by pellet group counts, trends and distribution of elk and deer range use in north central Arizona are presented. There have been no strong negative reactions to the primary vegetation treatments on the watersheds. There have been strong positive reactions to several treatments as a result of an increase in palatable, understory forage production.

**632. Neff, D.J. 1973. Effect of watershed treatment on deer and elk use. Arizona Game and Fish Department, Final Report, Arizona Federal Aid Project W-78-R-18; WP4, J5, Phoenix, Arizona, 9 pp.**

Estimates of deer and elk populations on ponderosa pine forest and pinyon-juniper woodland watersheds are summarized. Effects of pinyon-juniper woodland conversions and silvicultural treatments in ponderosa pine forests are presented.

**633. Neff, D.J. 1974a. Behavior of deer and elk in relation to watershed treatments. Arizona Game and Fish Department, Final Report, Arizona Federal Aid Project W-78-R-18; WP4, J14, Phoenix, Arizona, 22 pp.**

Winter and summer habitat use by deer and elk were observed on treated and untreated watersheds in north central Arizona.

**634. Neff, D.J. 1974b. Forage preferences of trained mule deer on the Beaver Creek watersheds. Arizona Game and Fish Department, Special Report No 4. Arizona Federal Aid Project W-78-R, 61 pp.**

Using tamed, trained mule deer, forage preferences in relation to vegetation treatments in ponderosa pine and pinyon-juniper were determined in north central Arizona.

**635. Neff, D.J. 1980a. Effects of watershed treatments on deer and elk range use. Arizona Game and Fish Department, Final Report. Arizona Federal Aid Project W-78-R; WP4, J5, Phoenix, Arizona, 37 pp.**

This report presents summaries of deer and elk responses over a 22 year period to vegetation treatments on Beaver Creek as determined by pellet group counts. There were no significant negative responses by deer or elk to any vegetation treatment on the watersheds. There were definite positive reactions by deer on the cleared watershed; by elk on the timber cleared and reseeded watershed; and by deer and elk on 4 other treated watersheds.

**636. Neff, D.J. 1980b. Occurrence of game forage plants on experimental watersheds. Arizona Game and Fish Department, Final Report. Arizona Federal Aid Project W-78-R, Work Plan 4, J13. 41 pp.**

Aggressive annual forbs and grasses are strongly favored by overstory removal and soil disturbance in north central Arizona. Some perennial species were also released by overstory removal. A marked increase in species diversity and forage production was observed where the soil was disturbed by treatment activity.

**637. Neff, D.J.; Wallmo, O.C.; Morrison, D.C. 1965. A determination of defecation rate of elk. Journal of Wildlife Management 29:406–407.**

Defecation rate of elk held in captivity was determined. This information allows managers to predict changes in population size.

**638. Neff, D. J.; McCulloch, C.Y.; Brown, D.E.; Lowe, C.H.; Barstad, J.F. 1979. Forest, range, and watershed management for enhanced wildlife habitat in Arizona. Arizona Game and Fish Department, Special Report No. 7.**

This report examines land-management practices and proposes policies that will enhance wildlife habitat values while producing high yields of water, wood, forage, and recreational opportunity.

**639. Patton, D.R. 1974a. Characteristics of ponderosa pine stands selected by the Abert's squirrel for cover. PhD Dissertation, University of Arizona, Tucson, Arizona.**

A small watershed in north central Arizona was stratified into 3 crown density (CD) classes to compare nest-tree density with CD of pine. Stands with less than 35% CD had 1 nest/9 acres; those with 36 to 70% CD contained 1 nest/4.5 acres. Highest nest density (1/2.1 acres) was in stands with over 70% CD.

**640. Patton, D.R. 1974b. Estimating food consumption from twigs clipped by the Abert squirrel. USDA Forest Service Research Note RM-272.**

Abert squirrels consume the inner bark of ponderosa pine twigs. Peeled twig mean length was 88 mm, diameter was 5.9 mm and dry weight was 1.3 g. A table provides the dry weight of inner bark from dry weight of peeled twigs. Nutrient content of inner bark was low.

**641. Patton, D.R. 1975a. Nest use and home range of three Abert squirrels as determined by radio tracking. USDA Forest Service Research Note RM-281.**

Abert squirrels used more than 1 nest in their home range. Three squirrels used 2 nests in a 30 acre area, 5 nests in a 10 acre area, and 6 nests in a 85 acre area.

**642. Patton, D.R. 1975b. Abert squirrel cover requirements in southwestern ponderosa pine. USDA Forest Service, Research Paper RM-145.**

This report describes characteristics of ponderosa pine trees and stands selected by Abert squirrels for cover including basal area, tree density and size, tree vigor, dominance and age class, nest location, and nest tree density.

**643. Patton, D.R. 1977. Managing southwestern ponderosa pine for the Abert squirrel. Journal of Forestry 25(5):265–268.**

Abert squirrels preferred all-aged stands of ponderosa pine. Nests were built in groups of trees with interlocking crowns. Habitat can be assured if trees are regenerated by the group selection method.

**644. Patton, D.R. 1984. A model to evaluate Abert squirrel habitat in uneven-aged ponderosa pine. Wildlife Society Bulletin 12(4):408–414.**

Tree size, density, and sociability were used to develop a model for evaluating Abert squirrel habitat quality. Habitat capability was determined for 5 quality classes by using an exponential regression model.

**645. Patton, D.R. 1991. Chapter 8. The ponderosa pine forest as wildlife habitat. In: Tecle, A. and W.W. Covington, Technical editors. 1991. Multiresource management of southwestern ponderosa pine forests: The status of knowledge. USDA Forest Service, Southwestern Region Report, pp. 361–410.**

Wildlife habitat includes abiotic and biotic components in a situation where organisms survive in a community relation. Within the pine ecosystem are smaller terrestrial communities composed of stands and stringers of gambel oak, aspen, riparian, and wet meadows, and aquatic communities. Existing knowledge of these communities within the pine ecosystem is reviewed because of their direct influence on maintaining the unique character and existence of each associated community.

**646. Patton, D.R.; Ffolliott, P.F. 1975. Selected bibliography of wildlife and habitats for the Southwest. USDA Forest Service, General Technical Report RM-16.**

This paper contains 390 selected references from 1913 to early 1975 on research and management of important wildlife and habitats in Arizona and New Mexico, A subject index is keyed to an alphabetical author list.

**647. Patton, D.R.; Hudak, H.G.; Ratcliff, T.D. 1976. Trapping, anesthetizing and marking the Abert squirrel. USDA Forest Service, Research Note RM-307.**

To capture Abert squirrels, folding live traps were placed at 250-ft intervals on a 1,000-ft grid to provide a density of approximately 2 traps/acre. Procedures are described for anesthetizing squirrels for physical examination. Squirrels were marked with ear tags and colored collars.

**648. Patton, D.R.; Ratcliff, T.D.; Rodgers, K.J. 1976. Weight and temperature of the Abert and Kaibab squirrels. The Southwestern Naturalist 21(2):236–238.**

Weights of male and female squirrels increased from spring to fall. In October, male average weight was about 715 g; females weighed about 690 g. The range in body temperature (38.5 °C to 42.7 °C) indicates that the Abert squirrel may be heterothermic.

**649. Pearson, H.A. 1968. Thinning, clearcutting, and reseeding affect deer and elk use of ponderosa pine forests in northern Arizona. USDA Forest Service, Research Note RM-119.**

Logging and slash disposal after thinning may decrease deer but increase elk populations. Deer and elk did not significantly affect forage use measurements.

**650. Reynolds, H.G. 1972. Wildlife habitat improvement in relation to watershed management in the Southwest. Arizona Watershed Symposium Proceedings 16:10–17.**

This report describes treatment impacts on habitat, and wildlife responses in ponderosa pine, pinyon-juniper, chaparral, and riparian habitats. Constraints on watershed treatments to improve wildlife habitat are recommended.

**651. Reynolds, H.G.; Clary, W.P.; Ffolliott, P.F. 1970. Gambel oak for southwestern wildlife. Journal of Forestry 68:545–547.**

Browse, mast, and cover produced by Gambel oak contribute substantially to wildlife sustainability. Gambel oak should be maintained in multiple-use ponderosa pine forests by management compromises with timber, water, and livestock interests.

**652. Szaro, R.C. 1976. Population densities, habitat selection, and foliage use by the birds of selected ponderosa pine forest areas in the Beaver Creek Watershed, Arizona. PhD Dissertation, Northern Arizona University, Flagstaff, Arizona.**

Measurements and evaluations of the effects of differing foliage volumes, foliage patterns, and trees densities on the diversity, density, and behavior patterns of breeding birds of the ponderosa pine forests in north central Arizona are presented. In addition, the effects of climate on the wintering birds of the pine forest and the standing crop biomass, consuming biomass, and existing energy requirements of the breeding birds on each plot are presented.

**653. Szaro, R.C.; Balda, R.P. 1975. The effects of seasonality on bird communities in the ponderosa pine forest. Proceedings, Cooper Ornithological Society Meeting, Montana State University, Bozeman.**

Effects of seasonality and foliage configuration on breeding bird communities in north central Arizona are presented.

**654. Szaro, R.C.; Balda, R.P. 1979a. Bird community dynamics in a ponderosa pine forest. Studies in Avian Biology, 3:1–66.**

The effects of habitat manipulation on the diversity, density, and behavior patterns of breeding birds in pine stands was measured. In addition, the standing crop biomass, consuming biomass, and existing energy requirements of breeding birds on each site was evaluated in north central Arizona.

**655. Szaro, R.C.; Balda, R.P. 1979b. Effects of harvesting ponderosa pine on nongame bird populations. USDA Forest Service Research Paper RM-212.**

Species diversity and richness were not significantly affected by forest cutting and logging except on the clearcut plot. Population densities were significantly increased on the silviculturally cut and irregular strip shelterwood plots and significantly decreased on the severely thinned and clearcut plots. Guidelines are recommended that will allow substantial logging while maintaining bird density, diversity, and species richness.

**656. Szaro, R.C.; Balda, R.P. 1982. Selection and monitoring of avian indicator species: An example from a**

**ponderosa pine forest in the Southwest. USDA Forest Service, General Technical Report RM-89.**

Factors involved in selecting an indicator bird species are highlighted by examination of a case study in north central Arizona. The pygmy nuthatch and violet-green swallow are suggested as indicator species for lightly cut to old growth Southwestern ponderosa pine.

**657. Szaro, R.C.; Balda, R.P. 1986. Relationships among weather, habitat structure, and ponderosa pine forest birds. Journal of Wildlife Management 50(2):253–260.**

Avian community structure during the breeding season in a ponderosa pine forest was influenced by weather and a series of timber harvest treatments. Fewer birds and bird species were present after a heavy snowfall winter with low temperatures than after milder winters.

**658. Szaro, R.C.; Brawn, J.D.; Balda, R.P. 1990. Yearly variation in resource-use behavior by ponderosa pine forest birds. Studies in Avian Biology, 13:226–236.**

Information on foraging patterns of breeding birds in a pine forest in northern Arizona are presented. Significant differences occurred for many species in activity patterns, foraging mode, tree species selection, substrate use, foraging posture, horizontal tree positioning, and vertical tree positioning.

**659. Turkowski, F.J. 1980. Carnivore food habits and habitat use in ponderosa pine forests. USDA Forest Service, Research Paper RM-215.**

The major food items of carnivores on the Beaver Creek watersheds (with percentages of scats in which each was found) were mammals 50%, birds 6%, reptiles 3%, arthropods 37%, and plants 60%. Although habitat manipulation influenced carnivore use of the treated watersheds, the modifications were harmless to most carnivore species.

**660. Urness, P.J.; Neff, D.J.; Vahle, J.R. 1975. Nutrient content of mule deer diets from ponderosa pine range. Journal of Wildlife Management 39(4):670–673.**

Although nutritional quality declined sharply from high in spring to moderate by late summer, this does not suggest deficiencies. Overall quality of summer diets was quite good. Very high values during late gestation should assure good milk production and optimum fawn production.

**661. Urness, P.J.; Neff, D.J.; Watkins, R.K. 1975. Nutritive value of mule deer forages on ponderosa pine summer range in Arizona. USDA Forest Service, Research Note RM-304.**

Chemical analyses and *in vitro* dry matter digestibles were obtained for monthly diets. Relative values were calculated based on nutrient contents and percentage composition in the diet. These data will help land managers assess impacts of vegetation management on mule deer habitat and in designing habitat improvements.

**662. Urness, P.J.; Smith, A.D.; Watkins, R.K. 1977. Comparison of *in vivo* and *in vitro* dry matter digestibility of mule deer forages. Journal of Range Management 30(2):119–121.**

*In vivo* digestibility percentages from digestion-balance trials were usually higher than *in vitro* determinations from the same experimental forage species.

**663. Wallmo, C. 1964. Arizona's "educated" deer. Wildlife Views 11(6):4–9.**

Some of the methodology needed and problems encountered when using pen-raised deer in north central Arizona to determine forage preferences is discussed.

**664. Wallmo, C.; Neff, D.J. 1970. Direct observations of tamed deer to measure their consumption of natural forage. In: Range of wildlife habitat evaluation—a research symposium. USDA Miscellaneous Publication 1147, pp. 105–110.**

The advantages and disadvantages of using tame deer in forage consumption studies are discussed.

## Wood Product Use

**665. Barger, R.L.; Ffolliott, P.F. 1964. Specific gravity of Arizona Gambel oak. USDA Forest Service, Research Note RM-19.**

Analytical procedures described by the USDA Forest Products Laboratory were used to estimate the specific gravity of 48 increment cores from sample trees 2.0 to over 11.0 inches in diameter at breast height. Mean specific gravity was 0.634, ranging from 0.706 to 0.569.

**666. Barger, R.L.; Ffolliott, P.F. 1965. Specific gravity of alligator juniper in Arizona. USDA Forest Service, Research Note RM-40.**

Analytical procedures described by the USDA Forest Products Laboratory were used to estimate the specific gravity of 46 increment cores from trees 2.0 to over 40.0 inches in diameter at breast height. Specific gravity ranged from 0.533 to 0.372.

**667. Barger, R.L.; Ffolliott, P.F. 1970. Evaluating product potential in standing timber. USDA Forest Service, Research Paper RM-57.**

An revision of USDA Forest Service Research Paper RM-15 is presented. Modifications in analytical methods and interpretations are described.

**668. Barger, R.L.; Ffolliott, P.F. 1971a. Effects of extractives on specific gravity of southwestern ponderosa pine. USDA Forest Service, Research Note RM-205.**

Estimates of specific gravity from unextracted and extracted samples are compared. Forms of extractives obtained are described.

**669. Barger, R.L.; Ffolliott, P.F. 1971b. Prospects for cottonwood utilization in Arizona. Progressive Agriculture in Arizona 23(3):14–16.**

Characteristics of the cottonwood resource and opportunities for using cottonwood for a variety of products are described. Although total acreage and volume of cottonwood in Arizona is not large, major concentrations are in the Verde, Little Colorado. and Gila River drainages.

**670. Barger, R.L.; Ffolliott, P.F. 1972. The physical characteristics and utilization of major woodland tree spe-**

cies in Arizona. USDA Forest Service, Research Paper RM-83.**

Woodland species in the Southwest, primarily Utah and alligator juniper, pinyon pine, and Gambel oak, represent a vast resource potentially useful for veneer, particle board, charcoal, pulp, and chemical extractives.

**671. Barger, R.L.; Ffolliott, P.F. 1976. Factors affecting occurrence of compression wood in individual ponderosa pine trees. Wood Science 8(3):201–208.**

Lean, either by itself or in combination with other visual tree characteristics, was an unreliable predictor of compression wood in northern Arizona. Release through thinning or partial cutting may substantially increase incidence of compression wood in trees that respond with increased growth rates.

**672. Ffolliott, P.F. 1977. Product potential of pinyon-juniper woodlands. In: Aldon, E. F., and T. J. Loring, technical coordinators. Ecology, uses, and management of pinyon-juniper woodlands: Proceedings of the workshop. USDA Forest Service, General Technical Report RM-38, pp. 28–31.**

Specific gravity and strength and related properties of pinyon and juniper tree species are presented. The relationships of these properties to product potential are also given. Increased use of the woodlands is suggested.

**673. Ffolliott, P.F.; Barger, R.L. 1967. Occurrence of stem features affecting quality in cutover southwestern ponderosa pine. USDA Forest Service, Research Paper RM-28.**

Much of the timber resource is the Southwestern United States is cutover ponderosa pine. Data from 3,779 sample trees in north central Arizona on occurrences of visual stem features (sweep, crook, lean, fork, scars, and knots) provide a method for appraising the suitability of major timber types for various products and the extent that stem defects reduce the product potential.

**674. Ffolliott, P.F.; Barger, R.L. 1976. Primary wood product recovery from cutover ponderosa pine timber in north-central Arizona. Arizona Agricultural Experiment Station, Miscellaneous Report 1.**

The volume and quality of primary products potentially recoverable from a clearcut stand are presented. The products considered include commercial poles, saw logs, veneer logs, stud logs, and pulpwood. Product alternatives for the timber in the stand are indicated.

**675. Ffolliott, P.F.; Clary, W.P. 1986. Pinyon-juniper woodlands in the Southwest. In: Ffolliott, P.F., and W.T. Swank, ed. Potentials of noncommercial forest biomass for energy. Arizona Agricultural Experiment Station, Technical Bulletin 256, pp. 3–10.**

Standing biomass, rate of biomass accumulation, residues, and energy management opportunities are considered in this paper. The need to direct management toward environmental considerations is stressed.

**676. Ffolliott, P.F.; Larson, F.R.; Barger, R.L. 1971. Predicting scaled volume recoverable from cutover southwestern ponderosa pine stands. USDA Forest Service, Research Note RM-195.**

The volume actually recoverable from harvesting timber can vary from the amount estimated by a volume table because of differences between assumed volume table use and actual logging practices, differences in timber form, and differences between stick-scaled and equation-calculated volumes. Tables are presented to provide a means of predicting scale volume recoverable from cutover ponderosa pine stands on sites of low and intermediate quality.

**677. Ffolliott, P.F.; Rasmussen, W.O.; Gottfried, G.J. 1983. Stem characteristic changes affect long-term planning for timber resource utilization. Forest Products Journal 33:57–60.**

Data from Southwestern ponderosa pine trees are used to illustrate how the occurrence and severity of stem characteristics change through time. Predicted changes in timber volumes suitable for various wood products, along with growth and yield information, can be used in optimization programs to make long-term timber resource decisions.

**678. Ffolliott, P.F.; Rasmussen, W.O.; Patterson, J.G. 1980. Biomass for energy: Potentials in Arizona. Bioresources Digest 2:240–247.**

Energy equivalents that characterize standing biomass and rate of biomass assimilation indicate that 5% of the state's energy needs could be met by renewable biomass supplies. The contribution to the energy requirements might be increased through intensified vegetative management conducted in a multiple-use framework.

**679. Fox, B.E. 1987. Fuelwood opportunities from Arizona pinyon-juniper stands. In: Everett, R.L., compiler. Proceedings of the Pinyon-Juniper Conference, Reno, Nevada, USDA Forest Service, General Technical INT-215, pp.173–176.**

Economic opportunities of removing fuelwood to increase water yield from pinyon- juniper stands in north central Arizona following a herbicide treatment are presented.

**680. Patterson, J.G. 1980. Potential energy equivalents of vegetation types in Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

Results of calculations based largely upon inventories of vegetative types on the Beaver Creek watershed are presented. Conversions to alternative expressions of energy equivalents are made in the framework of multiple-use management.

**681. Schlund, S.S. 1982. Potential energy equivalents of biomass residues from land management practices in Arizona. MS Thesis, University of Arizona, Tucson, Arizona.**

Quantification of residues are summarized by vegetative types on the Beaver Creek watersheds and elsewhere. Conversions to alternative expressions are presented.

**682. Senn, R.A., Jr. 1977. The effect of time on ponderosa pine stem form. MS Thesis, University of Arizona, Tucson, Arizona.**

Results from inventory plots on the Beaver Creek watershed formed the basis for this analysis. Multiproduct potentials are presented and compared to inventory summaries obtained 10 years earlier.

**683. Senn, R.A., Jr.; McMurtray, M.; Ffolliott, P.F.; Gottfried, G.J.; Larson, F.R. 1981. Effects of southwestern ponderosa pine mortality on potential wood product recovery. USDA Forest Service, Research Note RM-399.**

No differences were found between the quality of trees killed by natural causes (primarily lightning) and surviving trees. Mortality was 18% of the annual cubic foot increment.

## Dissertations And Theses

# Appendix A

**Representative Plant Species in 3 Vegetation Types on the Beaver Creek Watershed**

**Ponderosa Pine Forests**

Trees

| | |
|---|---|
| Arizona walnut | (*Juglans major* (Torr.) Heller) |
| alligator juniper | (*Juniperus deppeana* Steud.) |
| ponderosa pine | (*Pinus ponderosa* Laws.) |
| quaking aspen | (*Populus tremuloides Michx.*) |
| Rocky Mountain Douglas-Fir | (*Pseudotsuga menziesii* var. *glauca* Franco) |
| Gambel oak | (*Quercus gambelii* Nutt.) |

Shrubs

| | |
|---|---|
| Utah serviceberry | (*Amlanchier utahensis* Koehne) |
| greenleaf manzanita | (*Arctostaphylos patula* Greene) |
| Carruth sagebrush | (*Artemesia carruthii*) |
| Oregon grape | (*Berberis repens* Lindl.) |
| buckbrush | (*Ceanothus fendleri* Gray) |
| mountainmahogany | (*Cercocarpus* spp.) |
| cliffrose | (*Cowania mexicana* D. Don.) |
| hawthorn | (*Crataegus* spp.) |
| broom snakeweed | (*Gutierrezia sarothrae* Pursh) |
| common chokecherry | (*Prunus virginana* L.) |
| turbinella oak | (*Quercus turbinella* Greene) |
| buckthorn | (*Rhamnus* spp.) |
| sumac | (*Rhus* spp.) |
| New Mexico locust | (*Robinia neomexicana* A. Gray) |
| Arizona rose | (*Rosa arizonica* Rybd.) |

Forbs and half-shrubs

| | |
|---|---|
| yarrow | (*Achillea* spp.) |
| western ragweed | (*Ambrosia psilostachya*) |
| sagebrush | (*Artemisia* spp.) |
| aster | (*Aster* spp.) |
| thistle | (*Cirsium* spp.) |
| pine larkspur | (*Delphinium nelsoni* Greene) |
| spreading fleabane | (*Erigeron divergens* T. & G.) |
| trailing fleabane | (*E. flagellaris* Grey) |
| Fremont geranium | (*Geranium fremontii* Torr.) |
| orange sneezeweed | (*Helenium hoopesii* Gray) |
| common sunflower | (*Helianthus annuus* L.) |
| pinge | (*Hymenoxys richardsonii* Hook.) |
| grassleaf peavine | (*Lathyrus graminifolius* Wats.) |
| lupine | (*Lupinus* spp.) |
| Lambert crazyweed | (*Oxytropis lambertii* Prush.) |
| pyrola | (*Pyrola virens* Schweigg) |
| arrowhead | (*Sagittaria cuneata* Sheld) |
| Rocky Mountain sage | (*Salvia reflexa* Hornem.) |
| broom groundsel | (*Senecio spartioides* Torr. & Gray) |
| deer-ears | (*Swertia radiata* Kellogg) |
| meadowrue | (*Thalictrum fendleri* Gray) |
| salsify | (*Tragopogon* spp.) |
| Dakota verbena | (*Verbena bipinnatifida* Nutt.) |
| American vetch | (*Vicia americana* Muhl.) |
| showy goldeneye | (*Viguiera multiflora* Nutt. Blake) |

Grasses and grass-like plants

| | |
|---|---|
| quackgrass | (*Agropyron repens* L.) |
| bluestem wheatgrass | (*A. smithii* Rydb.) |
| big bluestem | (*Andropogon gerardii* Vitm.) |
| pine dropseed | (*Blepharoneuron tricholepis* (Torr.) Nash.) |
| blue grama | (*Bouteloua gracilis* (H.B.K.) Lag.) |
| mountain brome | (*Bromus marginatus* Neis.) |
| fringed brome | (*B. ciliatus* L.) |
| foxtail brome | (*B. rubens* L.) |
| bluejoint reedgrass | (*Calamgrostis canadensis* Michx.) |
| sedge | (*Carex* spp.) |
| orchardgrass | (*Dactylis glomerata* L.) |
| timber danthonia | (*Danthonia intermedia* Vasey) |
| Arizona fescue | (*Festuca arizonica* Vasey) |
| tall mannagrass | (*Glyceria elata* Nash) |
| perennial ryegrass | (*Lolium perenne* L.) |
| prairie junegrass | (*Koeleria cristata* (L.) Pers.) |
| spike muhly | (*Muhlenbergia wrightii* Vasey) |
| mountain muhly | (*M. montana* (Nutt.) Hitchc.) |
| switchgrass | (*Panicum virgatum* L.) |
| mutton bluegrass | (*Poa fendleriana* (Steud.) Vasey) |
| Kentuckey bluegrass | (*P. pratensis* L.) |
| bottlebrush squirreltail | (*Sitanion hystrix* (Nutt.) J. G. Smith) |
| prairie wedgescale | (*Sphenopholis obtusata* Michx.) |
| black dropseed | (*Sporobolus interruptus* Vasey) |
| Pringle needlegrass | (*Stipa pringlei* Seribn.) |

**Pinyon-Juniper Woodlands**
(including alligator and Utah juniper sub-types)

Trees

| | |
|---|---|
| alligator juniper | (*Juniperus deppeana* Steud.) |
| one-seed juniper | (*J. monosperma* (Engelm.) Sarg.) |
| Utah juniper | (*J. osteosperma* (Torr.) Little) |
| common pinyon pine | (*Pinus edulis* Engelm.) |
| singleleaf pine | (*P. monophylla* Torr. & Frem.) |

Shrubs

| | |
|---|---|
| fringed sagebrush | (*Artemisia frigida* Willd.) |
| big sagebrush | (*A. tridentata* Nutt.) |
| Fremont mahonia | (*Berberis fremontii* Torr.) |
| rubber rabbitbrush | (*Chrysothamnus nauseosus* (Pall.) Britton) |
| blackbrush | (*Coleogyne ramosissima* Torr.) |
| cliffrose | (*Cowania mexicana* Don) |
| dalea | (*Dalea* spp.) |
| ephedra | (*Ephedra* spp.) |
| common winterfat | (*Eurotia lanata* (Pursh) Moq.) |
| toadflax penstemon | (*Penstemon linarioides* Gray) |
| shrub liveoak | (*Quercus turbinella* Greene) |
| skunkbush sumac | (*Rhus trilobata* Nutt.) |

gray horsebrush (*Tetradymia canescens* DC)
Half-shrubs
broom snakeweed (*Gutierrezia sarothrae* (Pursh) Britt. & Rusby)
rough mendora (*Menodora scabra* Gray)
Other woody perennials
agave (*Agave* spp.)
mammillaria (*Mammillaria* spp.)
sacahuista nolina (*Nolina microcarpa* Wats)
cholla pricklypear (*Opuntia* spp.)
yucca (*Yucca* spp.)
Forbs
western yarrow (*Achillea lanulosa* Nutt.)
Amaranth (*Amaranthus* spp.)
aster (*Aster* spp.)
pussytoes (*Antennaria* spp.)
groundcover milkvetch (*Astragalus humistratus* Gray)
milkvetch (*A.* spp.)
bundleflower (*Desmanthus cooleyi* (Eaton) Trel.)
fleabane (*Erigeron* spp.)
Wright eriogonum (*Eriogonum wrightii* Torr.)
euphorbia (*Euphorbia* spp.)
Arizona evolvulus (*Evolvulus arizonicus* Gray)
slender goldenweed (*Haplopappus gracillis* (Nutt.) Gray)
hymenopapus (*Humenopappus lugens* Greene)
hymenoxys (*Hymenoxys cooperi* (Gray) Cockerell)
bladderpod (*Lesquerella* spp.)
Lewis flax (*Linum lewisii* Pursh)
deervetch (*Lotus* spp.)
common hoarhound (*Marrubium vulgare* L.)
penstemon (*Penstemon* spp.)
desert phlox (*Phlox austrmontana* Coville)
knotweed (*Polygonum* spp.)
slimflower scurfpea (*Psoralea tenuiflora* Pursh)
common russianthistle (*Salsola kali* L.)
broom groundsel (*Senecio spartioides* Torr. & Gray)
groundsel (*S.* spp.)
nightshade (*Solanum* spp.)
globemallow (*Sphaeralcea* spp.)
verbena (*Verbena* spp.)
annual goldeneye (*Viguiera annua* (Jones) Blake)
Perennial grasses and grass-like plants
bluestem wheatgrass (*Aqropyron smithii* Rydb.)
red threeawn (*Aristida longiseta* Steud.)
sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.)
black grama (*B. eriopoda* Torr.)
blue grama (*B. gracilis* (H.B.K.) Steud.)
curlymesquite (*Hilaria belangeri* (Steud.) Nash)
galleta (*H. jamesii* (Torr.) Benth.)
prairie junegrass (*Koeleria cristata* (L.) Pers.)
wolftail (*Lycurus phleoides* H.B.K.)
red muhly (*Muhlenbergia repens* (Presl.) Hitchc.)
ring muhly (*Muhlenbergia torreyi* (Kunth) (Bush)
spike muhly (*M. wrightii* Vasey)
Indian ricegrass (*Oryzopsis hymenoides* (Roem. & Schult.) Ricker
vine-mesquite (*Panicum obtusum* H.B.K.)
mutton bluegrass (*Poa fendleriana* (Steud.) Vasey)
tumblegrass (*Schedonnardus paniculatus* (Nutt.) Trel.)
bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) J.G. Smith)
sand dropseed (*Soporobolus cryptandrus* (Torr.) Gray)
needleandthread (*Stipa comata* Trin. & Rupr.)
fluffgrass (*Tridens pulchellus* (H.B.K.) Hitchc.)
hairy tridens (*T. pilosus* (Buckl.) Hitchc.)
slim tridens (*T. muticus* (Torr.) Nash)
Annual grasses
sixweeks threeawn (*Aristida adscensionis* L.)
needle grama (*Bouteloua aristidides* (H.B.K.) Griseb.)
sixweeks grama (*B. barbata* Lag.)

**Semi-Desert Shrubs**

Shrubs
big sagebrush (*Artemisia tridentata* Nutt.)
fourwing saltbrush (*Atriplex canescens* (Pursh) Nutt.)
blackbrush (*Coleogyne ramosissima* Torr.)
common wintefat (*Eurotia lanata* (Pursh) Moq.)
Forbs
milkvetch (*Astragalus* spp.)
wild buckwheat (*Eriogonum* spp.)
lupine (*Lupinus* spp.)
crazyweed (*Oxytropis* spp.)
phlox (*Phlox* spp.)
Indianwheat (*Plantago purshii* Roem. & Schult.)
Perennial grasses and grass-like plants
threeawn (*Aristida* spp.)
bluestem wheatgrass (*Agropyron smithii* Rydb.)
blue grama (*Bouteloua gracilis* (H.B.K.) Lag)
sideoats grama (*B. curtipendula* (Michx.) Torr.)
galleta (*Hilaria jamesii* (Torr.) Benth.)
prairie junegrass (*Koeleria cristata* (L.) Pers.)
Indian ricegrass (*Oryzopsis hymenoides* (Roem. & Schult.) Ricker
mutton bluegrass (*Poa fendleriana* (Steud.) Vasey)
bottlebrush squirreltail (*Sitanion hystrix* (Nutt.) J. G. Smith)
alkali sacaton (*Sporobolus airoides* Torr.)
sand dropseed (*S. cryptandrus* (Torr.) Gray)
needleandthread (*Stipa comata* Trin. & Rupr.)

# Appendix B

**Representative Fauna in 3 Vegetation Types on the Beaver Creek Watershed**

### Ponderosa Pine Forests

| | |
|---|---|
| Big game | |
| elk | (*Cervus canadensis* (Erx.) Reyn.) |
| mountain lion | (Felis concolor L.) |
| wild turkey | (*Meleagris gallopavo* Linn.) |
| mule deer | (*Odocoileus hemionus* RAF) |
| white-tailed deer | (*O. virginianus couesi* Coues & Kell.) |
| javelina | (*Tayassu tajacu* L.) |
| black bear | (*Ursus americanus* Pall.) |
| Small carnivores | |
| coyote | (*Canis latrans* Say.) |
| bobcat | (*Lynx rufus* Schr.) |
| striped skunk | (*Mephitis mephitis* Schr.) |
| grey fox | (*Urocyon cinereoargenteus* LSchr.) |
| Small game and rodents | |
| golden-mantled ground squirrel | (*Citellus lateralis lateralls* Say.) |
| rock squirrel | (*C. variegatus* Erxl.) |
| porcupine | (*Erethizon dorsatum* Mearns) |
| least chipmunk | (*Eutamias minmus arizonensis* How.) |
| black-tailed jackrabbit | (*Lepus californicus* Gray) |
| long-tailed weasel | (*Mustela frenata arizonensis* Mearns) |
| desert wood rat | (*Neotoma lepida* Thm.) |
| deer mouse | (*Peromyscus maniculatus* Wag.) |
| raccoon | (*Procyon lotor* L.) |
| western harvest mouse | (*Reithrodontomys megalotis* Baird) |
| Abert's squirrel | (*Sciurus abertii* Wood.) |
| desert cottontail | (*Sylvilagus audubonii* Baird) |
| red squirrel | (*Tamisciurus hundsonicus* Mearns) |
| northern pocket gopher | (*Thomomys talopides kaibabensis* Gold.) |
| Gallinaceous birds, pigeons, doves, quail | |
| band-tailed pigeon | (*Columba fasciata* Say.) |
| mournign dove | (*Zenaida macroura* Linn.) |
| Hawks, vultures and owls | |
| goshawk | (*Accipiter gentilis* Linn.) |
| golden eagle | (*Aguila chrysaetos* Linn.) |
| great-horned owl | (*Bubo virginianus* Thm.) |
| red-tailed hawk | (*Buteo jamaicensis* Grm.) |
| turkey vulture | (*Cathartes aura* Linn.) |
| sparrow hawk | (*Falco sparverius* Linn.) |
| bald eagle | (*Haliaeetus leucocephalus* Linn.) |
| Non-game birds | |
| red-faced warbler | (*Cardellina rubrifrons*) |
| brown creeper | (*Certhia familiaris*) |
| common nighthawk | (*Chordeiles minor*) |
| common flicker | (*Colaptes aurates*) |
| western wood pewee | (*Contopus sordidulus*) |
| raven | (*Corvus corax*) |
| Steller's jay | (*Cyanocitta stelleri*) |
| hairy woodpecker | (*Dendrocopus villosus*) |
| yellow-rumped warbler | (*Dendroica coronata auduboni*) |
| Grace's warbler | (*D. graciae*) |
| western flycatcher | (*Empidonax difficilis*) |
| hermit thrush | (*Hylocichla guttata*) |
| gray-headed junco | (*Junco caniceps*) |
| dark-eyed junco | (*J. hyemalis oreganus*) |
| acorn woodpecker | (*Melanerpes formicivorous*) |
| mountain chickadee | (*Parus gambeli*) |
| black-headed grosbeak | (*Pheucticus melanocephalus*) |
| rufous-sided towhee | (*Pipilo erythrophthalmus*) |
| hepatic tanager | (*Piranga flava*) |
| western tanager | (*P. ludoviciana*) |
| rock wren | (*Salpinctes obsoletus*) |
| Say's phoebe | (*Sayornis saya*) |
| broad-tailed hummingbird | (*Selasphorus platycercus*) |
| mountain bluebird | (*Sialia corrucoides*) |
| western bluebird | (*S. mexicana*) |
| white-breasted nuthatch | (*Sitta pygmaea*) |
| chipping sparrow | (*Spizella passerina*) |
| yellow-bellied sapsucker | (*Syphyrapicus varius*) |
| violet-green swallow | (*Tachycineta thalassina*) |
| house wren | (*Troglodytes aedon*) |
| robin | (*Turdus migratorius*) |
| solitary vireo | (*Vireo solitarius*) |

### Pinyon-Juniper Woodlands

(including alligator and Utah juniper sub-types)

| | |
|---|---|
| Big game | |
| pronghorn antelope | (*Antilocapra americana* Ord.) |
| elk | (*Cervus canadensis* (Erx) Reyn) |
| mountain lion | (*Felis concolor* L.) |
| wild turkey | (*Meleagris gallopavo* L.) |
| mule deer (Rocky Mountain) | (*Odocoileus hemionus* Raf) |
| white-tailed deer (Coues) | (*O. virginanus couesi* Coues & Kell.) |
| javelina | (*Tayassu tajacu* L.) |
| black bear | (*Ursus americanus* Pall) |
| Smaller carnivores | |
| coyote | (*Canis latrans* Say.) |
| hog-nosed skunk | (*Concepatus mesoleucus* Lichtenstein) |
| bobcat | (*Lynx rufus* Schr.) |
| striped skunk | (*Mephitis mephitis* Schr.) |
| spotted skunk | (*Spilogale putorius* L.) |
| badger | (*Taxidea taxus* Schreber) |
| grey fox | (*Urocyon cinereoargenteus* Schr.) |

Small game and rodents

| | |
|---|---|
| Harris' antelope squirrel | (*Ammospermophilus harrisii* Audubon and Bachman) |
| white-tailed antelope squirrel | (*A. leucurus* Merriam) |
| ringtail | (*Bassariscus astutus* Lichtenstein) |
| porcupine | (*Erethizon dorsatum* L.) |
| cliff chipmunk | (*Eutamias dorsalis* Baird) |
| black-tailed jackrabbit | (*Lepus californicus* Gray) |
| Mexican vole | (*Microtus mexicanus* Saussure) |
| desert wood rat | (*Neotoma lepida* Thomas) |
| Mexican wood rat | (*N. mexicana* Baird) |
| white-throated wood rat | (*N. albiqula* Hartley) |
| brush mouse | (*Peromyscus boylii* Baird) |
| cactus mouse | (*P. eremicus* Baird) |
| silky pocket mouse | (*P. flavus* Baird) |
| white-footed mouse | (*P. leucopus* Rofinenque) |
| deer mouse | (*P. maniculatus* Wag.) |
| pinyon mouse | (*P. truei* Shufeldt) |
| raccoon | (*Procyon lotor* L.) |
| western harvest mouse | (*Reithrodontomys megalotis* Baird) |
| Arizona grey squirrel | (*Sciurus arizonensis* Coues) |
| rock squirrel | (*Spermophilus variegatus* Erxl.) |
| desert cottontail | (*Sylvilagus audubonii* Baird) |
| Botta's pocket gopher | (*Thomomys bottae* Eydoux and Gervais) |

Bats and shrews

| | |
|---|---|
| pallid bat | (*Antrozous pallidus* Le Conte) |
| big brown bat | (*Eptesicus fuscus* Palisot de Beauvois) |
| California myotis | (*Myotis californicus* Audubon and Bachman) |
| fringed myotis | (*M. thysanodes* Miller) |
| western pipistrelle | (*Pipstrellus hesperus* H. Allen) |
| lump-nosed bat | (*Plecotus townsendii* Cooper) |

Gallinaceous birds, pigeons and doves

| | |
|---|---|
| band-tailed pigeon | (*Columba fasciata* Say) |
| Mearn's (or Harlequin) quail | (*Crytonyx montezumae* Vigors) |
| Gambel's quail | (*Lophortyx gambelii* Gambel) |
| mourning dove | (*Zenaida macroura* L.) |

Water birds

| | |
|---|---|
| spotted sandpiper | (*Actitis macularia* L.) |
| green-winged teal | (*Anas carolinensis* Gmelin) |
| cinnamon teal | (*A. cyanoptera* Vieillot) |
| blue-winged teal | (*A. discors* L.) |
| mallard | (*A. platyrhynchos* L.) |
| great blue heron | (*Ardea herodias* L.) |
| lesser scaup | (*Aythya affinis* Eyton) |
| redhead | (*A. americana* Eyton) |
| killdeer | (*Charadruis vociferous* L.) |
| western sandpiper | (*Ereunetes mauri* Cabanis) |
| least sandpiper | (*Erolia minutilla* L.) |
| American coot | (*Fulica americana* Gmelin) |
| eared grebe | (*Podiceps caspicus* Hablizl) |
| pied-billed grebe | (*Podilymbus podiceps* L.) |
| shoveler | (*Spatula clypeata* L.) |

Hawks, vultures and owls

| | |
|---|---|
| Cooper's hawk | (*Accipiter cooperii* Bonaparte) |
| golden eagle | (*Aquila chrysaetos* L.) |
| great horned owl | (*Bubo virginianus* Gmelin) |
| zone-tailed hawk | (*Buteo albonotatus* Kaup) |
| red-tailed hawk | (*B. jamaicensis* Gmelin) |
| turkey vulture | (*Cathartes aura* L.) |
| marsh hawk | (*Circus cyaneus* L.) |
| sparrow hawk | (*Falco sparverius* L.) |
| bald eagle | (*Haliaeetus leucocephalus* L.) |
| great horned owl | (*Otus anio* L.) |
| whiskered owl | (*O. trichopsis* Wagler) |
| osprey | (*Pandion haliaetus* L.) |
| barn owl | (*Tyto alba* Scopoli) |

Non-game birds

| | |
|---|---|
| white-throated swift | (*Aeronautes saxatalis* Woodhouse) |
| scrub jay | (*Aphelocoma coerulescens* Bosc) |
| Mexican jay | (*A. ultramarina* Bonaparte) |
| whip-poor-will | (*Caprimulgus vociferus* Wilson) |
| canon wren | (*Catherpes mexicanus* Swainson) |
| common nighthawk | (*Chordeiles minor* Forester) |
| red-shafed flicker | (*Colaptes cafer* Gmelin) |
| western wood pewee | (*Contopus sordidulus* Sclater) |
| common crow | (*Corvus brachyrhynchos* Brehm) |
| common raven | (*C. corax* L.) |
| Arizona woodpecker | (*Dendrocopos arizonae* Hargitt) |
| black-throated gray warbler | (*Dendroica nigrescens* Townsend) |
| gray flycatcher | (*Empidonax wrightii* Baird) |
| Rivoli's hummingbird | (*Eugenes fulgens* Swainson) |
| pinon jay | (*Gymnorhinus cyanocephalus* Wied) |
| hermit thrush | (*Hylocichla guttata* Pallas) |
| Scott's oriole | (*Icterus parisorum* Bonaparte) |
| oregon junco | (*Junco oreganus* Townsend) |
| Townsend's solitaire | (*Mayadestes townsendi* Audubon) |
| belted kingfisher | (*Megaceryle alcyon* L.) |
| acorn woodpecker | (*Melanerpes formicivorus*) |
| ash-throated flycatcher | (*Myiarchus cinerascens* Lawrence) |
| olivaceous flycatcher | (*M. tuberculifer* Lafresnaye & D'Orbigry) |
| mountain chickadee | (*Parus gambeli* Ridgeway) |
| plain titmouse | (*P. inornatus* Gambel) |
| bridled titmouse | (*P. wollweberi* Bonaparte) |
| cliff swallow | (*Petrochelidon pyrrhonota* Vieillot) |
| hepatic tanager | (*Piranga flava* Vieillot) |
| rock wren | (*Salpinctes obsoletus* Say) |
| broad-tailed hummingbird | (*Selasphorus platycercus* Swainson) |
| painted redstart | (*Setopaga picta* Swainson) |
| mountain bluebird | (*Sialia currucoides* Bechstein) |

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| western bluebird | (*S. mexicana* swainson) |
| pygmy nuthatch | (*Sitta pygmaea* Vigors) |
| yellow-bellied sapsucker | (*Sphyrapicus varius* L.) |
| chipping sparrow | (*Spizella passerina* Bechstein) |
| Bewick's wren | (*Thryomanes bewickii* Audubon) |
| Cassin's kingbird | (*Tyrannus vociferans* Swainson) |
| western kingbird | (*T. verticalis* Say) |
| solitary vireo | (*Vireo solitarius* Wilson) |
| gray vireo | (*V. vicinior* Coues) |
| white-throated swift | (*Zonotrichia leucophrys* Forster) |

### Semi-Desert Shrubs

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| **Big game** | |
| prong-horned antelope | (*Antilocapra americana* Ord) |
| mountain lion | (*Felis concolor* L.) |
| mule deer | (*Odocoileus hemionus* Raf.) |
| white-tailed deer | (*O. virginianus* Zimm.) |
| javelina | (*Tayassu tajacu* L.) |
| **Smaller carnivores** | |
| coyote | (*Canis latrans* Say.) |
| bobcat | (*Lynx rufus* Schr.) |
| hooded skunk | (*Mephitis macroura* Lich.) |
| striped skunk | (*Mephitis mephitis* Schr.) |
| spotted skunk | (*Spilogale putorius* L.) |
| badger | (*Taxidea taxus* Schr.) |
| grey fox | (*Urocyon cinereoargenteus* Schr.) |
| **Small game and rodents** | |
| Harris' antelope squirrel | (*Ammospermophilus harrisii* Aud. & Bach.) |
| ringtail | (*Bassariscus astutus* Lichtenstein) |
| porcupine | (*Erethizon dorsatum* Mearns) |
| black-tailed jack rabbit | (*Lepus californicus* Gray) |
| white-throated wood rat | (*Neotoma albigula* Hartl.) |
| southern grasshopper mouse | (*Onychomys torridus* Coves) |
| Arizona pocket mouse | (*Perognathus amplus* Osgood) |
| rock pocket mouse | (*P. intermedius* Merriam) |
| cactus mouse | (*Peromyscus eremicus* Baird) |
| white-footed mouse | (*P. laucopus* Raf.) |
| raccoon | (*Procyon lotor* L.) |
| western harvest mouse | (*Reithrodontomys megalotis* Baird) |
| desert cottontail | (*Sylvilagus audubonii* Baird) |
| valley pocket gopher | (*Thomomys bottae* Eydoux & Gervais) |
| **Bats and shrews** | |
| big brown bat | (*Eptesicus fuscus* Beauv.) |
| California myotis | (*Myotis californicus* Aud. & Bach.) |
| desert shrew | (*Notiosorex crawfordi* Coves) |
| western pipistrelle | (*Pipistrellus hesperus* H. Allen) |
| Mexican free-tailed bat | (*Tadareda brasiliensis* St-Hil.) |
| **Gallinaceous birds, pigeons, doves, and quail** | |
| Gambel's quail | (*Lophortyx gambelii* Gambel) |
| white-winged dove | (*Zenaida asiatica*) |
| mourning dove | (*Z. macroura* L.) |
| **Hawks, vultures, and owls** | |
| golden eagle | (*Aquila chrysaetos* L.) |
| great horned owl | (*Bubo virginianus* Gmelin) |
| red-tailed hawk | (*Buteo jamaicensis* Gmelin) |
| prairie falcon | (*Falco mexicanus* Schl.) |
| peregrine falcon | (*Falco peregrinus* Tuns.) |
| sparrow hawk | (*F. sparverius* L.) |
| turkey vulture | (*Lathastes aura* L.) |
| screech owl | (*Otus asio* L.) |
| **Non-game birds** | |
| black-throated sparrow | (*Amphispiza bilineata* Cass.) |
| cactus wren | (*Campylorphynchus brunneicapillus* Lafr.) |
| house finch | (*Carpodacus mexicanus* Muller) |
| canyon wren | (*Catherpes mexicanus* Swain.) |
| Gila woodpecker | (*Centurus uropygilalis* Baird) |
| lesser nighthawk | (*Chardules acutipennis* Herm.) |
| gilded flicker | (*Colaptes chrysoides* Malh.) |
| common raven | (*Corvus corax* L.) |
| ladder-backed woodpecker | (*Dendrocopos scalaris* Wagler) |
| road runner | (*Geococcyx californianus* Lesson) |
| loggerhead shrike | (*Lannis ludovicianus* L.) |
| mockingbird | (*Mimus polyglottos* L.) |
| house sparrow | (*Passer domesticus* L.) |
| phainopepla | (*Phainopepla nitens* Swain.) |
| brown towhee | (*Pipilo fuscus* Swain.) |
| black-tailed gnatcatcher | (*Polioptila melanura* Swain.) |
| vermilion flycatcher | (*Pyrocephalus rubinus* Bodd.) |
| cardinal | (*Richmondena cardinalis* L.) |
| rock wren | (*Salpinctes obsoletus* Say.) |
| phoebe | (*Sayornis saya* Bona.) |
| crinssal thrasher | (*Toxostoma dorsale* Henry) |
| curve-biled thrasher | (*T. curvirostre* Swain.) |
| white-crowned sparrow | (*Zonotrichia leucophrys* Foister) |

RMRS
ROCKY MOUNTAIN RESEARCH STATION

The Rocky Mountain Research Station develops scientific information and technology to improve management, protection, and use of forests and rangelands. Research is designed to meet the needs of National Forest managers, federal and state agencies, public and private organizations, academic institutions, industry, and individuals.

Studies accelerate solutions to problems involving ecosystems, range, forests, water, recreation, fire, resource inventory, land reclamation, community sustainability, forest engineering technology, multiple use economics, wildlife and fish habitat, and forest insects and diseases. Studies are conducted cooperatively, and applications can be found worldwide.

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