VEGETATION MANAGEMENT FOR WATER YIELD IN THE SOUTHWEST

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The Southwest (Arizona and New Mexico) is a region of comparatively low water yields. Most streamflow is now impounded and subject to consumptive use; ground water sources are being rapidly depleted. Moreover, an increasing population is demanding more water per individual. Hence, there is urgent need to develop watershed management practices that will ensure the optimum quantity and quality of water, consistent with other returns from watersheds, such as timber, forage, wildlife, and recreation.

This paper analyzes some of the factors influencing water yields, reviews some principles of vegetation management in relation to water yields, and indicates some possibilities for favoring water yields of Southwestern watersheds. Recommendations are based largely upon the watershed management research program of the U. S. Forest Service in Arizona, which was designed to obtain fundamental information for improving management of watershed lands in the Southwest (Price and Hoover, 1957). Intensive research is now conducted in most major vegetation types (Reynolds, 1959A).

Water yield management is emphasized. Other important areas of watershed management, such as flood control, and stabilization or rehabilitation of deteriorated watersheds, are mentioned only incidentally.

General Physical Characteristics

In general, the Southwest lies within the southern portion of the Rocky Mountain uplift. Elevations range from 137 feet along the Colorado River in southwestern Arizona to above 14,000 feet in the Sangre de Cristo mountains of northcentral New Mexico. Topography is extremely variable, ranging from high, rough, mountainous terrain to low, desert, alluvial plains.

Climate varies from tropical in the low, hot valleys to arctic in the higher mountains. Mean daily temperatures during the summer range from about 90°F in the deserts to less than 50°F in the mountains; average annual temperatures vary from over 70°F to less than 40°F.

Average annual rainfall is less than three inches in southwestern Arizona and more than 35 inches in the high mountains of northern New Mexico. April-through-September (growing season) precipitation varies from about 40 percent of the total annual in western Arizona to over 75 percent in eastern New Mexico.

Vegetation in the Southwest varies with the many different climatic conditions. For any given area, vegetation is an expression of the interactions of climate, parent soil material, and geologic history of plant complexes. The main vegetation types of the Southwest, as referenced to dominant plants, are: arctic-alpine, spruce-fir-aspen, pine-fir, ponderosa pine, pinyon-juniper, chaparral, sagebrush, mixed grassland, desert grassland, desert shrub, and cresote bush (Fig. 1).

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WATER YIELDS

Areas of Yield

In general, precipitation increases and temperature decreases with a rise in elevation. As a result, the higher water-yielding areas of the Southwest are associated mostly with the higher elevations (Fig. 1).

The highest water-yielding lands are located in the headwaters of the Rio Grande and San Juan Rivers in Colorado where water yields may exceed 35 inches annually. Higher lands of the Sangre de Cristo and San Juan Mountains in New Mexico produce from 10 to 30 inches annually. In Arizona, the best water-yielding zones are found along the Mogollon Plateau, where annual yield is about two to ten inches.

Areas yielding more than 10 inches annually make up less than two percent of the total land area of the Southwest. Annual yields from one to 10 inches makes up about 10 percent of the area (Reynolds, 1960). Thus, about 12 percent of the land area of the Southwest contributes nearly 65 percent of the water yield; and 50 percent yields about 90 percent of the flow (Fig. 1).

Several relations are evident when water yields are compared for the different vegetation types (Fig. 2). Interpretations of these data are conservative since most of them are limited to only two or three years of precipitation-runoff measurements. In this regard, Rich (1959), in analyzing three years' data in the ponderosa pine type near Alpine, Arizona, stated that the first year was characterized by very little runoff, the second year by much runoff from a summer precipitation, and the third year by runoff from snowmelt. Glendening (1959) noted similar variations among and within chaparral watersheds near Prescott, Arizona.

In general, streamflow decreases with elevation as does precipitation. Exceptions suggest, however, that other factors in addition to total annual precipitation determine water yield. The alligator-juniper watershed on Beaver Creek seems to be a particularly good water producer. This may be associated with rain falling on snow-covered or moisture-saturated soils.

Most water appears to be yielded during the winter months. In spite of Arizona's receiving about one-half of its precipitation during the summer months, only a small portion is yielded as streamflow.

March and April consistently seem to be months of highest streamflow. When streams are primarily snow-fed, April appears to produce highest streamflow. The Willow Creek spruce and the Beaver Creek alligator-juniper watersheds are good examples.

Perennial streams from small watersheds seem to be the exception in Arizona. Confluence of several small, high-elevation watersheds is necessary to produce a perennial stream.

Precipitation Distribution and Water Yield

Period of year in which precipitation falls affects timing and amount of streamflow. For the growing season (April through September), the percent of total rainfall varies from less than 40 percent in western Arizona to more than 75 percent in eastern New Mexico.

The importance of winter precipitation in producing streamflow is shown by data from experimental watersheds on the Sierra Ancha Experimental Forest. Here, 87 to 93 percent of total streamflow is yielded during the winter season. About 65 percent of total annual rainfall fell during this period (Table 1).

Variation in Streamflow

Streamflow of Southerwestern rivers is highly variable. The following tabulation compares relative variability of runoff from the Verde River and rainfall for Prescott for the period 1901-1960:

	Rainfall	Runoff
Coefficient of variation (%)	33.9	68.5
Coef. vs[2/]	7.70	7.60

Both annual rainfall and runoff are highly variable, as indicated by the coefficients of variation; there is a great tendency for high and low years to occur in groups. Also, runoff appears to be more variable than rainfall, possibly because of the complicating effects of difference in sequence of storms, antecedent moisture in the soil, and storm intensities.

Vegetation Characteristics and Streamflow

In addition to kind, amount, intensity, and distribution of precipitation, numerous other factors also affect streamflow. Important factors are: (1) drainage basin characteristics, such as nature and form of rock, and shape, size, slope, and channel density; and (2) the soil-plant complex. Although plants and soil are interrelated, they are discussed separately where possible.

When precipitation first encounters a vegetated watershed, some moisture is retained by the foliage. The amount varies with the kind, density, height, and arrangement of the canopy. In the pine-fir type of the Sierra Anchas, Cable[3/] measured interception of 34 percent for storms of less than one-half inch, and 13 percent for storms more than one-half inch. In pole-sized stands of ponderosa pine in northern Arizona, Aldon (1959) found between 11 and 25 percent of the gross rainfall intercepted, with sparse stands intercepting significantly less rainfall than dense stands. These values for interception are similar to those obtained elsewhere in the United States (Kittredge, 1948).

Litter that accumulates under a cover of vegetation retains a certain amount of moisture; but also protects the soil from raindrop impact, reduction of which may improve infiltration and reduce moisture loss from deeper soil

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[2/] The coef. vs was devised by Clawson (1947) to test the tendency for above- and below-average years to occur in "bunches." Clawson (1950) classifies a coef. vs above 4.0 as "high."

[3/] Cable, D. R., Unpublished data in files of Rocky Mountain Forest and Range Experiment Station, Tempe, Arizona.

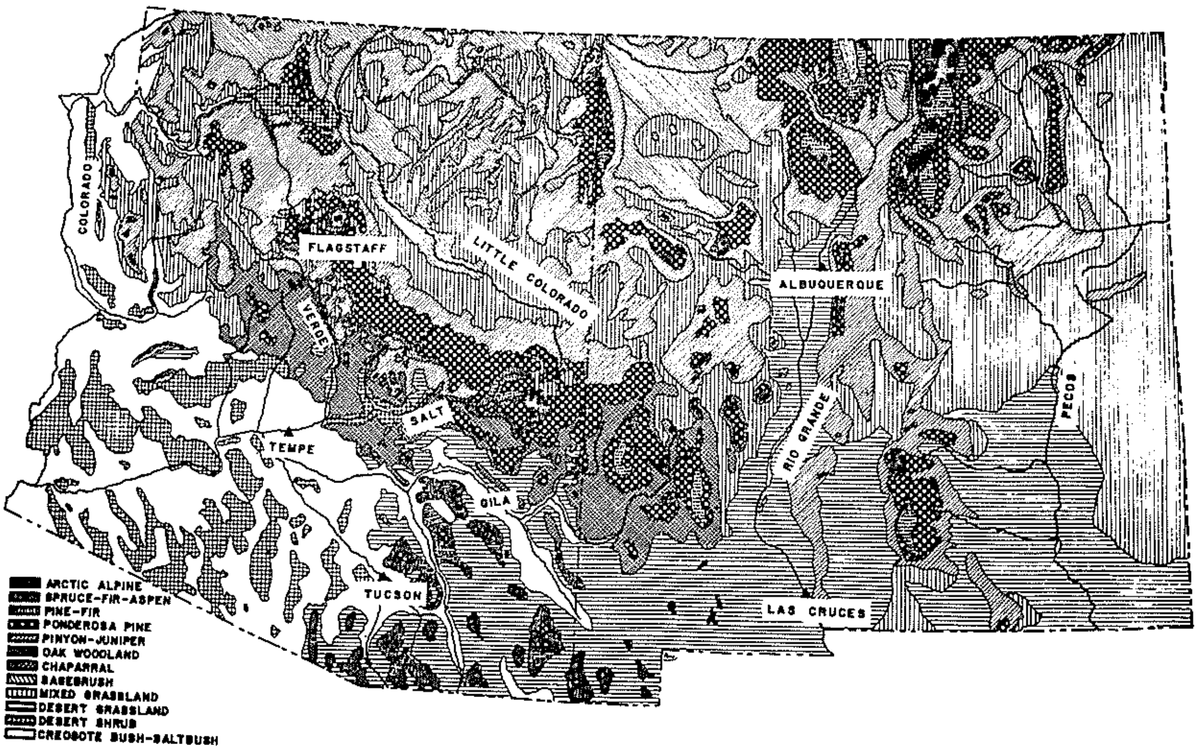
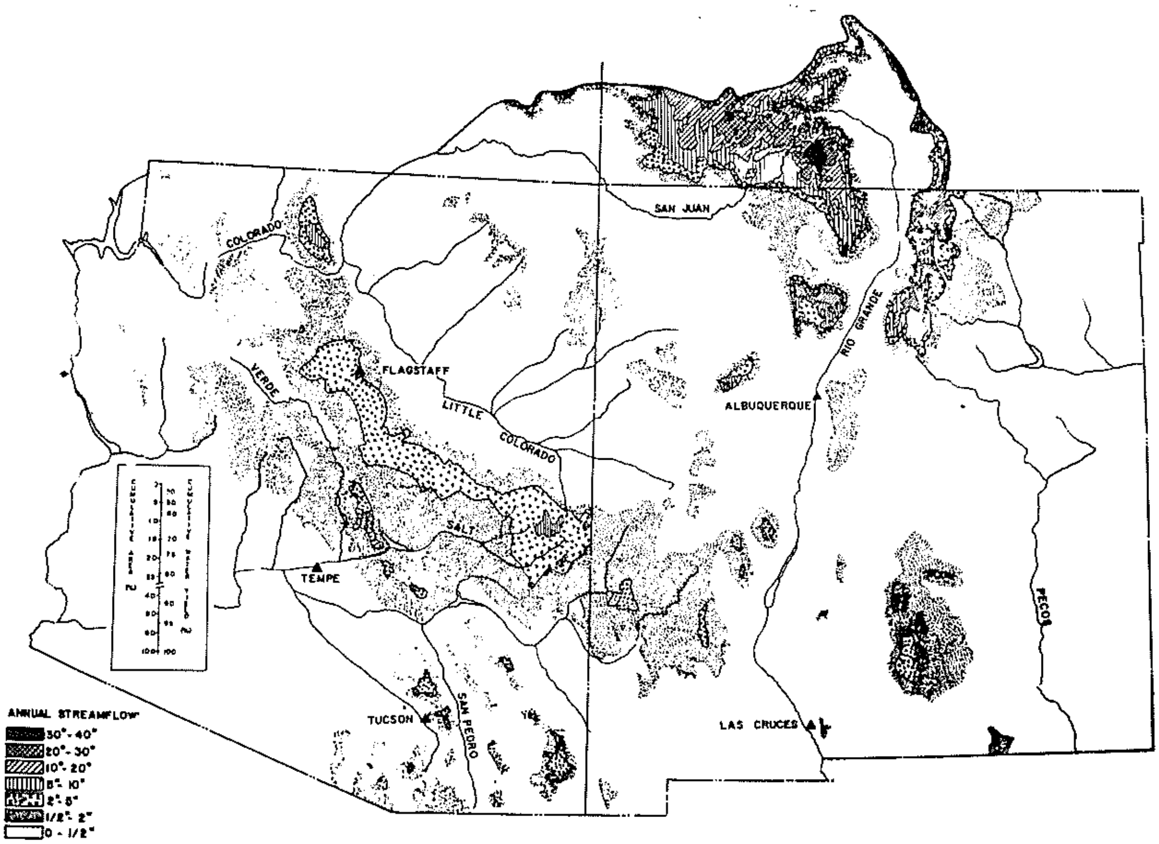


Figure 1. Above - Major vegetation types of the Southwest (Arizona, after Nichol, 1952; New Mexico, after Castetter, 1956). Below Location of important water-yielding areas in the Southwest (Source: Soil Conservation Service preliminary compilation of annual water yields of some Southwestern states).



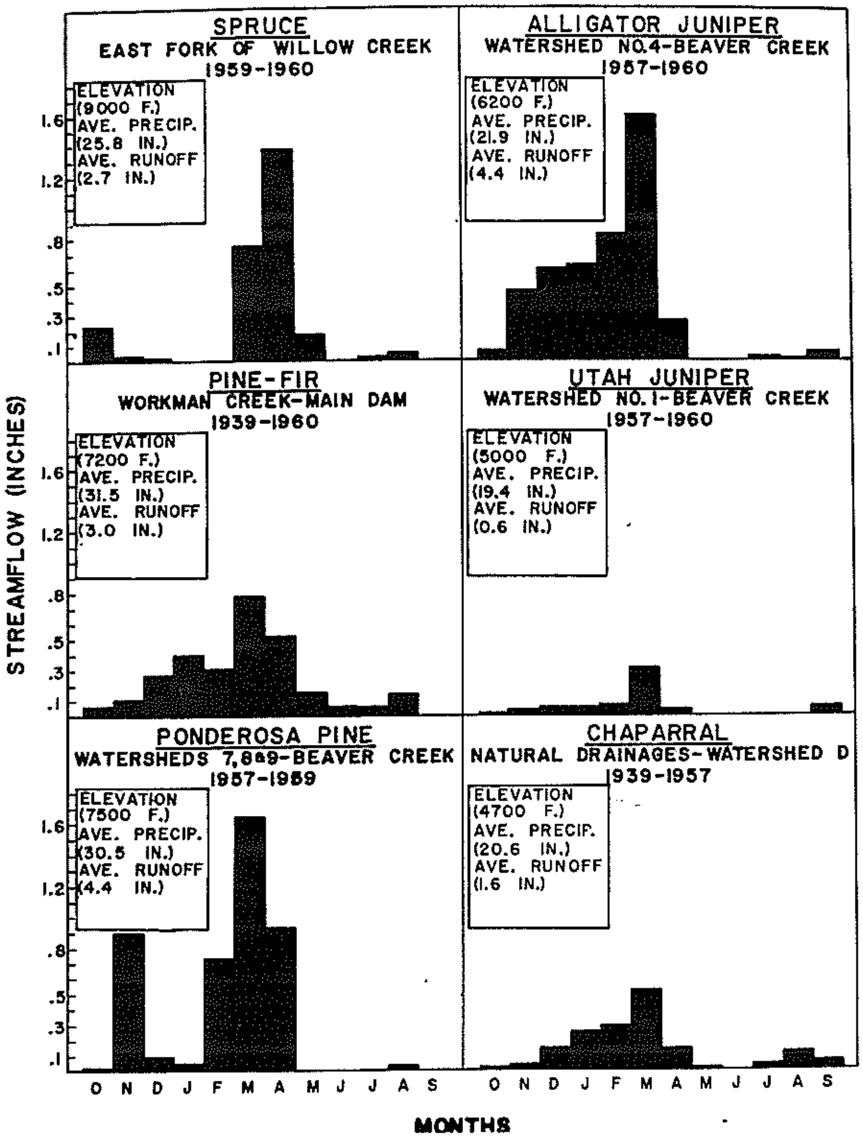


Figure 2. Monthly streamflow distribution from watersheds located in several vegetation types of the Southwest.

layers. Aldon (1959) found a gross rainfall loss of seven to 25 percent from four to 21 tons per acre of litter accumulated under pole-sized stands of ponderosa pine. Studies elsewhere in Canary Island pine suggest, however that a litter layer reduces soil moisture losses under a stand of trees as compared with soil moisture losses from bare soil in the open (Kittredge, 1954).

Soil affects the hydrologic characteristics of a watershed. It determines infiltration, or the rate of water movement into the soil; percolation, or the rate of downward water movement; and storage capacity.

Structure, number, size, shape, and stability of mineral and organic aggregates in the soil largely determine size, shape, and distribution of soil pores. A good cover of vegetation promotes favorable pore-space relations (Lassen, Lull, and Frank, 1952). Thus, vegetation by affecting pore space has an important influence upon how water moves into, through, and is held by the soil.

Moisture entering the soil is either retained in storage or is contributed to streamflow and deep seepage. Water is mostly removed from the soil by transpiration. Rapid loss of moisture below the surface foot can be attributed largely to root penetration and absorption (Storey, 1958).

Total evapotranspiration for a given site increases with solar radiation, vapor pressure deficit, wind, absorption of incident radiation by soil and plant surfaces, and as the amount of moisture in the root zone increases (Thornthwaite and Hare, 1955). This means that such characteristics of vegetation as composition, density, arrangement, and depth of root penetration influence evapotranspiration. Several management possibilities for favorably affecting streamflow may thus be hypothesized, such as:

1. Reducing the abundance or prolification of root systems in the soil mantle.

2. Substituting plants with shallow rooting habits for those with deep root systems.

3. Replacing plants of short growing seasons for those of longer growth and water-use periods.

4. Decreasing the size of vegetation by substituting:

    a. Tall-growth forms for low-growth forms.

    b. Young-age classes for old-age classes.

5. Reducing the density of the vegetation cover consistent with maintenance of soil stability.

6. Decreasing soil litter to the level where its protective effect on soil moisture loss is balanced against its interception loss.

7. Changing stand distribution and arrangement to favorably influence water yield from snow, and to reduce turbulence and air movement within and around a stand.

Table 1.--Relative contributions of winter and summer rainfall to seasonal runoff for four experimental watersheds on the Sierra Ancha Experimental Forest.

Vegetation type	Period	Rainfall				Streamflow				"F" values (Winter vs. summer)
		Winter		Summer		Winter		Summer		
		Inches	Percent	Inches	Percent	Inches	Percent	Inches	Percent	
WORKMAN CREEK (7,000 feet; 1,087 acres)										
Pine-fir	1939-53	20.29	65.6	10.56	34.3	2.47	87.0	0.37	13.0	61.71**
PARKER CREEK (6,700 feet; 700 acres)										
Pine-fir	1939-57	15.71	63.3	9.11	36.7	5.08	88.8	.51	11.2	54.42**
POCKET CREEK (6,500 feet; 900 acres)										
Pine-chaparral	1937-57	14.44	64.4	7.99	35.6	2.53	92.7	.20	7.3	44.33**
NATURAL DRAINAGE "D" (4,500 feet; 9 acres)										
Chaparral	1935-57	12.19	63.2	7.09	36.8	1.37	86.2	.22	23.8	11.55**

VEGETATION MANAGEMENT

Under the present system of extensive management (compared to intensive management of agricultural lands), management of watershed lands must be confined largely within the framework of possibilities of ecological succession. "Ecological succession is the orderly process of community change; it is the sequence of communities which replace one another in a given area." (Odum, 1953).

Any given plant community is largely an expression of the available resources of the entire site, resulting from the geologic history of the organisms (both plants and animals), as modified by recent history (fire, land use, etc.). The community is, however, dynamic and not static. It is continually being modified in quality, quantity, and proportion because of changes in the substrate, influence of plants upon the substrate, and interactions among the organisms themselves (Dansereau, 1957).

Community relations and successional phenomena for vegetation types of the Southwest are not completely understood. However, some general relationships are known, and progress is being made toward a better understanding of these and of others now largely unknown.

A generalized version of some successional sequences for the more important vegetation types of Arizona and New Mexico from the standpoint of water yield management are outlined below:

Arctic-alpine.--Castetter (1956) describes general successional sequences. On dry sites, the sequence consists of a moss-lichenforb stage, followed by a fairly stable cover of alpine tundra grasses, including bluegrasses (*Poa* spp.), wheatgrasses (*Agropyron* spp.), oatgrasses (*Danthonia* spp.), and fescues (*Festuca* spp.). On wet sites, sedges and rushes, represented by *Juncus*, *Luzula*, and *Kobresia*, dominate.

Spruce-fir-aspen.--The stable community consists of Englemann spruce (*Picea englemannii* Parry), and subalpine (*Abies lasiocarpa* (Hook.) Nutt.) or cork-bark fir (*A. lasiocarpa* var. arizonica (Merriam) Lemm.), with lesser amounts of blue spruce (*Picea pungens* Engelm.), white fir (*Abies concolor* (Gord. and Glend.) Lindl.), and Douglas fir (*Psedotsuga menziesii* (Mirb.) Franco).

When the type is opened up by logging or fire, quaking aspen (*Populus tremuloides* Michx.) or grasses and forbs characteristic of the subalpine grassland take over (Fig. 3). If aspen is removed, perennial grasses fully occupy the sites (Castetter, 1956).

Pine-fir.--White fir and Douglas fir are climax, occurring in mixture with ponderosa pine (*Pinus ponderosa* Lawson). Pure stands of Douglas fir sometimes develop. On drier sites, or where the stand has been opened up by logging of moister sites, ponderosa pine is a conspicuous element of the forest community.

With disturbance, such as heavy logging, New Mexico locust (*Robinia neomexicana* A. Gray) and bracken (*Pteridium aquilinum* (L.) Kuhn) become prominent in the understory (Fig. 3). With catastrophic wildfire, which destroys the overstory, bracken dominates for a few years, is overtopped by

New Mexico locust, which is again eventually suppressed by conifers.

Ponderosa pine.--Pure stands of ponderosa pine occur over extensive areas between 7,500 and 6,000 feet in Arizona, and at the lower, drier reaches of the coniferous association in New Mexico. Where the canopy is open and where grazing has not been excessive, Arizona fescue (Festuca arizonica Vasey) and mountain muhly (Muhlenbergia montana (Nutt.) Hitchc.), and miscellaneous grasses and forbs are abundant in the understory.

Occasionally, gambel oak (Quercus gambelii Nutt.) and New Mexico locust establish compact thickets in breaks in the forest. Where the canopy is dense, the ground floor may be almost bare of vegetation (Nichol, 1952). On rocky ridges or otherwise dry sites, other shrubs may be abundant including: cliffrose, (Cowania mexicana D. Don), buckbrush (Ceanothus spp.), serviceberry (Amelanchier spp.), mountain mahogany (Cercocarpus spp.), and manzanita (Arctostaphylos spp.).

The successional sequence resulting from various combinations of heavy logging, grazing, and cultivation for the ponderosa pine type of northern Arizona is fairly well known (U.S. Forest Service, 1951). When a ponderosa pine forest is logged over, understory midgrasses increase in abundance to dominate the understory. Under too heavy or improper grazing, succession then passes through retrogressive stages of: short grasses, prostrate perennial weeds, short-lived half shrubs, annuals, to bare ground. Logging denudation or unsuccessful farming of bunchgrass openings may take the succession to bare ground directly. Progressive succession may follow the reverse series of stages, or skip several stages, depending on the seed supply, conditions for germination and establishment, and grazing pressure.

Successional stages are somewhat different with a shrub understory, particularly where wildfire has occurred. In transition with chaparral and alligator juniper (Juniperus deppeana Steud.), ponderosa pine can be converted to these species by wildfires. Where gambel oak, New Mexico locust, Fendler ceanothus (Ceanothus fendleri Gray), or manzanita exist in the understory, destructive wildfire will change ponderosa pine to a dominance of these species (Chapline and Talbot, 1959).

Pinyon-juniper.--In the tension zone between pinyon-juniper woodland and grassland or chaparral, juniper tends to invade. Upon removal of juniper by mechanical and chemical means or by fire, grasses or shrubs again dominate. Under too heavy or otherwise improper grazing, grasslands pass through retrogressive successional stages, as for the ponderosa pine type (Arnold and Schroeder, 1955).

Chaparral.--The sequence of woody plant replacements in the absence of wildfire is not known for the chaparral type of Arizona and New Mexico. However, where a grass-shrub mixture exists shrubs will take over and fully occupy the site as perennial grasses are eliminated.

Something is known of the response of the type to wildfire (Cable, 1957; Pond, 1960). Most chaparral species sprout from root crowns when fire destroys above-ground parts; other species seed in rapidly after a burn because germination of seeds lying in the soil is enhanced by heat. Crown cover of shrubs appears to regain prefire conditions in seven to 10 years. Repeated

Figure 3. Examples of forest succession in Arizona. Above - Progressive succession. Young white firs and Douglas firs in the understory should eventually overtop the aspen and dominate the site. Below - Retrogressive succession. (Left) New Mexico locust in the understory is suppressed by overtopping, young pines. When dominating conifers were destroyed by wildfire (right), locust was released.

burning seems to favor the more prolific sprouters. Hence, under a combination of heavy grazing and repeated burning, when shrubs are growing in mixture, the type tends to be dominated by or to form a pure stand of shrub live oak (Quercus turbinella Greene) or manzanita.

PRELIMINARY RESEARCH RESULTS ON VEGETATION MANAGEMENT FOR WATER YIELD

Some management opportunities for favorably affecting water yields on different vegetation types are discussed in the following section. These are merely suggestions and are presented to show some possibilities. Firm recommendations will depend on more intensive research.

Spruce-fir.--Ecologically, it appears possible to manage many sites in this type for almost pure cover of perennial grass, aspen, or conifers. Thus, from the standpoint of water yield, water comparisons among these three kinds of plant cover are important.

The problem is being approached by periodic sampling of soil moisture beneath plant communities at three different sites in the White Mountains. No statistical differences in soil moisture levels for the same community were found at the beginning and end of the water year in 1960. However, when water use was compared among communities during the period of soil moisture recession (April - September), quaking aspen appeared to use significantly more water than spruce or grass, with no significant differences between the latter. Additional years of sampling will be necessary to verify this indication.

Water savings were indicated when the cover was changed from aspen to herbs in Utah (Croft, 1950). Water saving was estimated to be about four inches annually. Shallower root systems and less draft on moisture in the soil mantle among the herbaceous plants were thought to account for the difference in water use.

Preliminary measurements suggest that soil freezing may also affect water yields in the spruce-aspen-fir type of White Mountains, Arizona. In 1959-60, snow cover was greatest under grass, then aspen, and least under conifer. An inverse relation existed between snow cover less than two feet deep and depth of freezing; frost disappeared faster, the lesser the snow depth. Water may be yielded over the frost mantle, the shallower mantles yielding earlier and more water.

Pine-fir.--Ecologically, there are a number of possibilities for vegetation management in the pine-fir type. Working down the succession scale, development could be arrested at any of the following ecological stages: mixed conifer-chrub, conifer-shrub-grass, shrub-grass, or perennial grass.

Studies on the Workman Creek experimental watersheds in the Sierra Anchas were designed to determine: (1) water yield difference between the ecological extremes, and (2) the effect of advanced timber management practices upon water yield and sedimentation.

The Workman Creek watersheds are located in the pine-fir type of the Sierra Ancha Mountains between elevations of 6,590 to 7,725 feet. The major watershed contains three subwatersheds--North Fork of 248 acres, Middle Fork of 521 acres, and South Fork of 318 acres. Watersheds were calibrated between 1938 and 1953. At that time, a timber management cut was made on South Fork; and broadleaved trees were removed along the stream bottom in North Fork; Middle Fork served as a climatic check.

By the fall of 1958, no measureable change in streamflow could be detected from removing broadleaved trees along North Fork. This may be accounted for by the very small percentage of the total tree canopy that was removed when the broadleaved trees were cut. After the site was cleared, it was planted to perennial grasses and slash was largely consumed by burning (Rich, 1960).

Two years of streamflow data, following the moist-site cut, indicate that water yield has been increased (Rich, 1960). In 1959, actual streamflow exceeded predicted flow by 0.5 inch; in 1960, the difference increased to 2.0 inches. Additional years of varied climatic characteristics must be measured before an average difference, based upon statistical analysis, can be established.

No statistical change in water yield has been measured on South Fork since the cessation of timber cutting in 1955. This was in spite of a wildfire in 1957, which virtually destroyed all trees on 60 acres along one side of the watershed. Immediately after the fire, there was displacement of superficial layers of soil on the burn to lower reaches and channels of the watershed; also, peak flows increased. Lack of change in water yield can possibly be attributed to deeper soils than on North Fork and to water use of New Mexico locust, which now dominates on the burn (Rich, Reynolds, and West, 1959).

Ponderosa pine.--Because of its extensive area (particularly in Arizona), easy accessibility, and fair growth rates, the ponderosa pine type is the most important timber-producing region in the Southwest. Fairly intensive management effort is directed to this end, although other values of the type, such as water, range, wildlife habitat, and recreation are recognized.

On Beaver Creek, watersheds are being calibrated for testing water yield differences between ponderosa pine and perennial grass to bracket the ecological-economic possibilities (Kennedy, 1959). Other watersheds are also being calibrated to determine whether reducing stand density of ponderosa pine, to that judged optimum for timber yield, will affect water yield. At present, 80 square feet of basal area per acre is recommended as about optimum for timber production (Gaines and Kotok, 1954)(Fig. 4).

Pinyon-juniper.--This type in both Arizona and New Mexico serves as important range for livestock and game. At the lower elevations, pinyon-juniper mostly joins a grassland type. In many areas, juniper has invaded the grasslands. Ranchers, and State and Federal agencies, are now removing juniper from many sites to improve grasslands (Arnold and Schroeder, 1955) (Fig. 4). The possible effect that removing juniper and restoring grassland has upon water yield is being approached at Beaver Creek in two ways: one by soil moisture sampling, the other by means of experimental watersheds.

Soil moisture differences in the upper two feet of cleared areas of Utah juniper (Juniperus osteosperma (Torr.) Little) and alligator juniper were

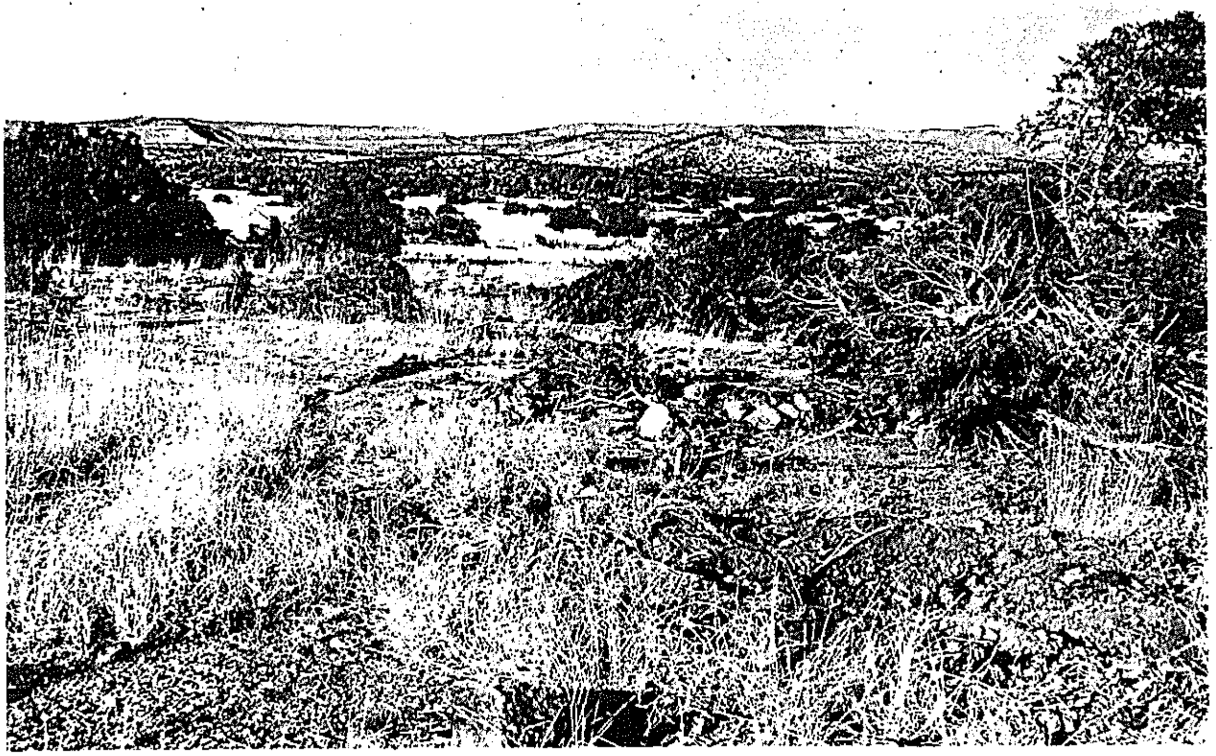


Figure 4. Land improvement practices in the ponderosa pine and pinyon-juniper types. The effect of these practices upon water yield and sedimentation are being tested on experimental watersheds at Beaver Creek, Arizona. Above - Unthinned, pole-sized, ponderosa pine on left; properly thinned stand on right. Below - Pinyon-juniper removed in area of invasion to help restore grassland to full production.

checked against adjacent uncleared areas between June 1959 through September 1960. Differences between juniper-infested and juniper-cleared areas of small magnitude were recorded only during spring and early summer. Thus, although there is a tendency toward increased water yields, unit yield will probably be small. However, small increases in water yield from an area as large as the pinyon-juniper type could make important contributions to total water yields.

Similar soil moisture differences have been observed in the pinyon-juniper type at Pine Flat, New Mexico. Soil moisture was measured in the upper 12 inches of soil under three cover conditions--pinyon trees, herbaceous cover (mostly blue grama (*Bouteloua gracilis* (H.B.K.) Lag.), and bare soil. It was concluded, as a result of these measurements, that replacement of pinyon trees with herbaceous vegetation would not have an appreciable effect upon water yields through percolation except during those years when precipitation was above average during the winter dormant season (Dortignac, 1956).

On Beaver Creek, *experimental watersheds* in both alligator and Utah juniper types (three in each type) are now being calibrated to later test the effect of juniper removal upon water yield. Two-and three-fold increases in grass are known to occur after juniper removal (Arnold and Schroeder, 1955), which is now an accepted range practice. If proper grazing is practiced after juniper removal, increased perennial grass cover should result in greater soil stability. Evaluation of the effect of juniper removal upon water yield must await calibration and treatment of the experimental watersheds.

Chaparral.--Chaparral occurs along the Mogollon front in Arizona and extends into the southern foothills of the Gila Mountains of Arizona. A proper mixture of shrubs and grass should benefit both livestock and game. One method of achieving this management objective is to completely remove shrubs with a root plow and to seed adapted perennial grasses (Glendening, 1959). Some indication of the possible effects of converting from shrubs to perennial grass is being obtained from lysimeters and small watersheds.

Chaparral lysimeters at Sierra Ancha were planted to skunkbush sumac (*Rhus trilobata* Nutt.), and adjacent lysimeters were seeded to green sprangletop (*Leptachloa dubia* (H.B.K.) Nees.) in 1953. Preliminary comparisons suggest that during the spring period more water should be available for streamflow under the grass than under the shrub cover. Presumably, this difference is associated with earlier season of water use and deeper root system of skunkbush sumac.

Differences in water yield between perennial grass and chaparral are now being compared on four *small watersheds* in the mixed chaparral-grassland transition at Sierra Ancha Experimental Forest. After a calibration period, shrubs were poisoned on two of the four watersheds between 1953 and 1956. Perennial grass responded to shrub removal by increasing in abundance and volume almost immediately. Hence, a comparison exists between a perennial grass-shrub mixture and a perennial grass community.

A slight increase in streamflow was measured on the grass watershed in 1957. Whether or not this difference is statistically significant will necessitate further replication of years which sample a variety of rainfall conditions (Price, 1958).

Phreatophytes.--In the Southwest, most riparian situations from high mountains to desert elevations are occupied by various species of phreatophytes. The most abundant species at lower elevations is five-stamen tamarisk (Tamarix pentandra Pall.), an exotic. At intermediate elevations, Arizona sycamore (Platanus wrightii Watts.), cotton wood (Populus spp.), willows (Salix spp.), and box elder (Acer neguendo L.) may be abundant locally. At the highest elevations, alders (Alnus spp.), maples (Acer spp.), and willows often form dense stands along live streams (Horton, 1959). Robinson (1952) has estimated that such phreatophyte associations waste many acre feet of water annually. Management of these riparian sites should favor species that promote soil and streambank stabilization, have low water use, and satisfy demands for other utilitarian uses such as recreation and grazing.

Preliminary results suggest that there might be considerable water saving and improved grazing by substituting a Bermudagrass (Cynodon dactylon (L.) Pers.) cover for tamarisk. These indications were obtained by comparing evapotranspiration of naturally vegetated but undisturbed plots of tamarisk and grass simultaneously with plots containing Bermudagrass alone. The apparatus used for measuring evapotranspiration consisted of two transparent plastic tents with ventilating blowers, sampling systems, and a highly sensitive hygrometer (infrared gas analyzer) (Horton, Decker, and Gary, 1959).

The difference in water use is probably associated with amount and height of foliage exposed to the atmosphere. Other measurements have shown that the mid-day rate of evapotranspiration for Bermudagrass is consistently higher than that for an adjacent free water surface (Decker, Cole, and Gaylor, 1960).

WATER YIELD CHARACTERISTICS OF THE SOUTHWEST

1. Most water yield of the Southwest originates in the higher mountains; 12 percent of the area yields about 65 percent of the total runoff, these are the areas that will be more intensively managed for water in the future.

2. Most water yield in the Southwest originates from winter precipitation. Vegetation management directed towards maintenance of summer - rather than winter-growing plants should favor water yields (Rich, 1951). Moreover, if summer-growing species have shallow vs deep roots, short vs tall stature, and have a minimum density and litter accumulation consistent with soil stability, water yields should be further enhanced.

3. Streamflow in the Southwest is highly variable. Provisions should be made for storing flow during wet years by fully developing lakes, reservoirs, dams, and underground aquifers, whichever are economically most feasible and socially most desirable.

GENERAL MANAGEMENT CONCEPTS

1. Watersheds exhibit individually as to size, shape, slopes, depth of soils, geology, channel density, vegetation cover, and other factors that influence water yields. Study, treatment, and management should be directed toward individual watersheds insofar as possible in overall land management planning (Reynolds, 1959).

2. Stable vegetation on a watershed results in less overland flow, less erosion, and lower peak flows during flood, than mismanaged vegetation (Colman, 1953). In the management of watersheds, soil movement should not be permitted to exceed tolerable limits for maintaining low flood hazards, clear flows of water, and soil productivity. Moreover, induced overland flow is usually at the expense of subsurface flows and increases soil erosion (Martin and Rich, 1948).

3. Proper grazing of grass-shrub watersheds does not affect water yield detrimentally (Rich and Reynolds, 1960). This concept is corroborated by plot studies in Utah, Idaho, and Colorado, which indicate that if grazing leaves a protective plant cover, fairly good control over surface flow and erosion results (Colman, 1953).

SOME MANAGEMENT INDICATIONS FOR THE SOUTHWEST

1. In the spruce-fir-aspen type, there is indication that management could be directed toward a mixture with grass favored over aspen and conifer. The best areas for treatments and their size, shape, and relative positioning are unknown. Preliminary work is underway on the effect of different kinds of patch cuttings upon timber management (Kennedy, 1959). The effect of a patchy mixture of grass, spruce, and aspen upon livestock use, wildlife habitat, and recreation is yet to be determined.

2. In the pine-fir type, removal of forest and its replacement with grass along moist bottoms may enhance multiple use values (Rich, 1960). Less costly methods and higher economic social demands will be necessary before such undertakings are practical.

3. In the ponderosa pine type, thinning to 80-100 square feet of basal area per acre is now an accepted forest management practice for improving timber yields (Kennedy, 1959). The influence of this forestry practice on water, grazing, game, and recreation values is now being determined. There is a suggestion from foreign work that forest tree density may have to be reduced below this level to affect water yields favorably (McComb, 1959).

4. In the pinyon-juniper type, juniper removal to favor perennial grass in the woodland-grassland tension zone is a generally accepted range management practice (Arnold and Schroeder, 1954). Improved water yields at the higher elevations and on specific sites are indicated, but quantitative effects are yet to be established. Also, cover relations for game in a clearing program, though known to some degree (Jantzen, 1959), need to be further determined.

5. In the chaparral type, changing from a shrub to a perennial grass cover may favorably influence water yields, at least on specific sites. Forage production for livestock is known to be improved by such a practice. Information is still needed as to sites to be treated; arrangement, and size of converted areas; and specific species of shrubs and grass to provide the most desirable combination for optimum returns from water, range, and habitat for livestock and game.

6. At the lower elevations, removal of tamarisk and its replacement by Bermudagrass in riparian situations should benefit both water yield and livestock grazing (Horton, 1960). Any action program should give consideration to

channel stabilization and to effects upon game and recreational values.

Because of the need for additional data, particularly replication in time and space, the above recommendations must be considered as tentative. It is hoped, however, that some management directions, at least deserving of pilot testing, are indicated. Future progress of research will depend upon adequate financing, effective cooperation, and industry and good fortune among researcher in unraveling Nature's riddles.